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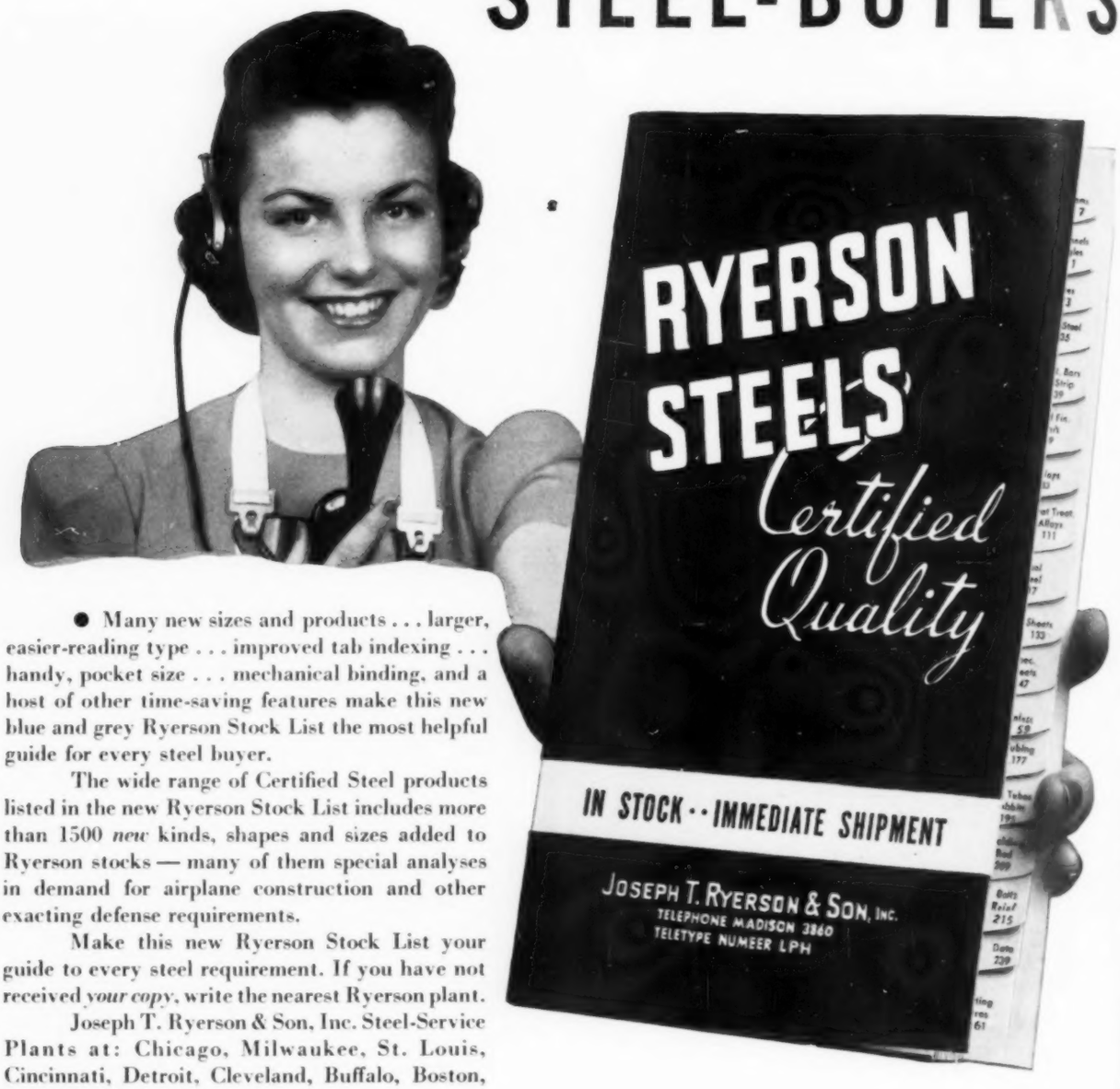

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CRITICAL POINTS

By The Editor

WITH ROBERT AMMON visited the new electrolytic zinc plant of American Zinc, Lead & Smelting Co. (of which he is chief metallurgist) at Monsanto, just over the river from St. Louis. Except for the motor-generator sets, all the buildings of the old Evans-Wallower refinery were stripped of their equipment, rusting for ten years, and a complete new plant installed in about five months, capable of making about 17,000 tons of slab zinc per year, and boosting the number of American electrolytic zinc plants to four. Association with a nearby smelter and oxide plant enables this new one to sidestep some difficult problems faced by others that must be self-sufficient; consequently the leaching and purification systems may be reduced to these bare essentials: (1) Leach, (2) separate solids, (3) purify solution, (4) final filtration. . . . . In the first step, roasted calcines are leached in a minimum of spent electrolyte plus acid, the slurry eventually reaching a substantially neutral condition wherein iron sulphate and added manganese dioxide eliminate the arsenic and antimony as basic iron salts. These leach tanks are agitated by means of revolving paddles. Although a single leach does not get all the zinc, much of the insoluble is contained in coarse solids which are separated in a drag classifier, and these unwashed sands are sent back to the zinc oxide plant and mixed with the furnace charge. Fine solids in the spigot discharge from Dorr thickeners are filtered, the filter cake (which contains all the lead sulphate and is destined for smelting) is washed just enough to balance cost of evaporating wash water against unrecovered zinc sulphate. . . . . Available concentrates from foreign and domestic sources are chosen so as to exclude those containing such pests as cobalt and germanium; the calcine sent to this plant is also low in iron and silica, to control the voluminous gelatinous precipitate when the clarified solution is purified by adding zinc dust. Copper and cadmium are thrown down in the final purification tank and filtered off, the clear filtrate being then ready for the electrolytic cells and the sludge ready for furnacing to recover its contained values. Owing to choice of suitable concentrates, some special final purifications are unnecessary to get 99.99 zinc from the electrolytic deposit. . . . . The cell-room is a model; solutions are cascaded through water-cooled, lead-lined tanks of concrete, six in series, to use currents of low density. Insoluble anodes (lead plus 1% silver) and aluminum cathodes are used; from the latter the zinc is stripped daily, washed, melted in a small reverberatory, and ladled out into slab molds. Owing to the limited capacity of the old electrical equipment, unusually massive copper bus-bars are installed, and every other precaution taken to reduce voltage losses.

America's Fourth Electrolytic Zinc Plant

TALKING with NORMAN STOTZ, metallurgical engineer of Universal-Cyclops Steel Corp., about problems in toolsteel hardening without soft skin, and he told the story of how a hardener in a small plant in Illinois some years ago came to a correct conclusion by a *non sequitor*, to wit: If a copper paint will stop off carburizing, the passage of carbon from outside to in, it ought to do the opposite, that is, prevent soft skin. He tried it and it worked just as well as borax, which melted, dripped off the tool, and was hard on his carborundum furnace hearth. . . . . Why copper paint *does* work in both cases is no metallurgical mystery, for the copper film, like a Nazi border guard, unquestionably halts *any* passage. It cares not whether the carbon comes from the methane gas on one side or from solid cementite on the other. No passage for carbon! However, the furnace conditions when carburizing

Dopes to Prevent Decarb

and when hardening are radically different, and the copper may lose its integrity. One atmosphere is not so hot and carburizing, the other hotter and decarburizing — else why take any trouble? The casehardening temperature is below the melting point of copper and the hardening of high speed steel is as far above, and often oxidizing. To those who have not yet got a real protective atmosphere and do not like a thin solution of borax, well drained, these prepared "stop-offs" are often useful. Seemingly suspensions of powdered chromium compounds (or oxides?) in water glass also work fairly well, and avoid the chance that copper in a non-oxidizing atmosphere will melt, alloy with the surface and even embrittle by penetrating the grain boundaries. (Has anyone tried to spray the copper on with a metalizing gun?) . . . . . P.S. STOTZ and other metallurgists who have seen these notes say there are some difficulties with the copper paint: *(a)* It is not too easy to get off. *(b)* Too little of it and you get soft spots; too much and you may blister a fine tool.

Porous Cr-Plate Cylinder Linings

COMES NOW a note concerning the advantages of a thick and adherent (but porous and corrosion resistant) tough chromium plate for stopping wear in air-engine cylinders — porous because it must give some anchor for the oil film, and corrosion resistant because much "wear" is caused by chemical reaction. One part of the problem is to get a strongly coherent and adherent plate, for a cylinder liner in an air-cooled engine is not just a liner, but its ⅛-in. thickness must also resist the explosive force of the gas. Any fragments of hard chromium broken off would be emery in the oil. Reports are that a successful method of making such a thick, dull plate has been developed by a Hollander, HENDRIK VAN DER HORST, and extensively used for lining diesel cylinders in England. The process is now being applied in America (at least experimentally) to small sized air engine cylinders and some varieties of piston rings. . . . . PAUL LANE of Muskegon Piston Ring Co. tells me that the relative wear resistance of very hard surfaces (like chromium plate and nitrided steel) and softer ones like hardened alloy steels cannot be readily stated. Much depends on surface smoothness and mounting of the rubbing parts. Strangely enough, extreme smoothness is likely to involve considerable "blow-by" and large oil consumption for a long breaking-in period. Likewise a surface that does not wear has no "gasket action", or ability to adjust itself to permanent size changes and bore conditions due to heat or mechanical stresses. A certain degree of roughness and a certain (but slow) rate of wear seem to be essential for correct functioning of piston rings against the cylinder wall. Furthermore, the expected life or overhaul period of the engine is worthy of consideration; if a combination that is good for the minimum 5000 hr. can be more readily and quickly manufactured than another combination that does not wear at all, the former would be approved for mass production in the present emergency.

A Deep Dark Secret

CHASED myself around in a circle trying to find out how much tungsten exists in the Government stockpiles, in order to get a complete statement of our present resources in this essential metal. Armed with a letter from JESSE JONES, administrator of the Federal Loan Agency, confirming published figures of holdings by Metals Reserve Co., visited the Procurement Division of the Treasury Department which had been authorized to acquire tungsten in a law passed in 1939 and required by that same law to report transactions annually to Congress. It was no trouble to see the tungsten man in Procurement, but he flashed a regulation preventing any disclosure of information without an order signed by Mr. MORGENTHAU, and suggested a call at the Information Service in the Treasury Building. Taxied over there only to draw a blank; the obliging clerk said Mr. KNUDSEN's Office of Production Management had the figures. Enroute, stopped by the Bureau of Mines, and the statistician was uncertain whether the difference between receipts and American consumption measured the stockpile, because the Bureau's figures for imports come from the Custom House, and he was uncertain whether imports by the Treasury would require payment of duty, and so be reported. Continuing on to OPM, found that the figures could not be released without permission from the Procurement Division of the Treasury, and I was back to where I started! . . . . . A final source of information even a year old was closed, for the Report of the Secretary of the Treasury to Congress for the year ending June 30, 1940 was not to be found, even in the Library of Congress.

TROUBLES WITH CRACKED METHANOL AS AN ATMOSPHERE FOR HEAT TREATING

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WITHIN the last few years a considerable number of atmospheres have been developed for the protection of steel during heat treatment. Although an almost unlimited number of compositions are available, consideration of cost has limited such atmospheres to a very few types. The first such protective atmosphere was produced by the partial combustion of hydrocarbons, principally methane (natural gas), propane or butane, originally piped directly from generator to furnace, but later treated for the removal first of water and then of carbon dioxide. The most recent generators of this type will permit almost perfect combustion and nearly completely remove the water and carbon dioxide, and so produce an atmosphere of over 99.5% nitrogen.

Another type of atmosphere is produced by combining the oxygen in the air with carbon, either in a carbonaceous muffle or in a charcoal gas generator, to provide an atmosphere high in nitrogen and carbon monoxide but with at least traces of hydrogen and methane. In the most recent generators of this type the theoretical composition of 34% carbon monoxide and 66% nitrogen, produced by the perfect combustion of air and carbon, can be approached. Equipments for forming and purifying protective atmospheres were described in METAL PROGRESS last month by Messrs. SLOWTER and GONSER.

The third type of atmosphere is produced by cracking or dissociation of certain chemical compounds — such as hydrocarbons, alcohols and anhydrous ammonia. Such atmospheres, where practical, are of interest primarily because of their easy control and because the small investment in generating equipment would permit their use on small furnaces used intermittently. Among the numerous chemicals suggested and tested for this purpose is wood alcohol or methanol (CH_3OH). B. W. GONSER, in *Metals and Alloys*, July 1937, and *Heat Treating and Forging*, May, 1939, has published curves showing this atmosphere to be mildly decarburizing for short periods at 1562° F. and strongly decarburizing for longer periods at 1742° F.

Prior to the publication of GONSER's results this atmosphere was tested by us at The Hoover Company with very erratic results. At various times it was tried in three different production furnaces (and also in the laboratory, using a carbon combustion furnace from an analytical train) at temperatures of 1550° F. and 1820° F. In the laboratory furnace and two production furnaces the atmosphere proved mildly carburizing, but in the fourth large heat treating furnace it decarburized an S.A.E. 1015 steel leaving the surface almost carbon free!

Recently some work has been done to deter-

mine the reason for such a wide variation in results, and our conclusions, published by kind permission of The Hoover Company, may be of rather general interest.

The three production furnaces used in these tests were of the same type (electrically heated, vertical carburizers made by the Hevi Duty Electric Co.) although in one the retort was 24 in. deep and 29 in. in diameter, and in the other two the retorts were smaller: 20 in. deep and 10 in. in diameter. The retort in the large furnace and in one of the small ones was the NC-4 alloy, 35% nickel and 15% chromium, and in the other small furnace it was the 60% nickel, 20% chromium, 20% iron alloy. The combustion furnace used in the laboratory had the usual small quartz tube. However, since decarburization occurred in one of the NC-4 retorts and mild carburization in another NC-4 retort at the same temperature, the variation in results could not logically be ascribed to any catalytic effect of the alloy in the retorts.

In all these preliminary trials the methanol was cracked in the furnace. That is to say, methanol was dripped into a pipe leading directly into the hot zone, and the only apparent difference in the operations was the route by which the alcohol entered the furnace. The two smaller retorts were ordinarily used for carburizing and were equipped with a fan inside the cover to circulate the carburizing gases. The motor, mounted above the lid to operate the fan, was of such a size that the pipe from the methanol reservoir came down at one side to a point below the motor, then turned at an angle of about 30° to a point nearer the center of the retort, where it again turned to pass vertically through the lid into the retort. (See Fig. 2.) Under these conditions the liquid methanol dropped through the vertical pipe to the first turn, where it struck the side of the pipe and then flowed at a relatively slow rate down the side of the pipe to be volatilized before it reached the interior. In fact it "cracked" or decomposed as the gas went along at a variety of indeterminate but increasing temperatures as it passed through the cover. In these furnaces and under these conditions carbon toolsteel and high speed steel containing 0.75% carbon could be carburized with cracked methanol.

In the larger furnace, however, a small pipe from the methanol reservoir was centered, through a reducer, in a larger vertical pipe which passed directly through the furnace cover. (See Fig. 1.) Under these conditions the methanol dropped, *as a liquid*, directly into the hot retort and was vaporized and cracked substantially at one temperature, the heat treating temperature. (Steel samples placed directly under this tube, admitting the methanol, bore a stain showing where the liquid landed.) In this larger furnace the cracked methanol atmosphere proved definitely decarburizing, especially at the higher temperature of 1820° F.

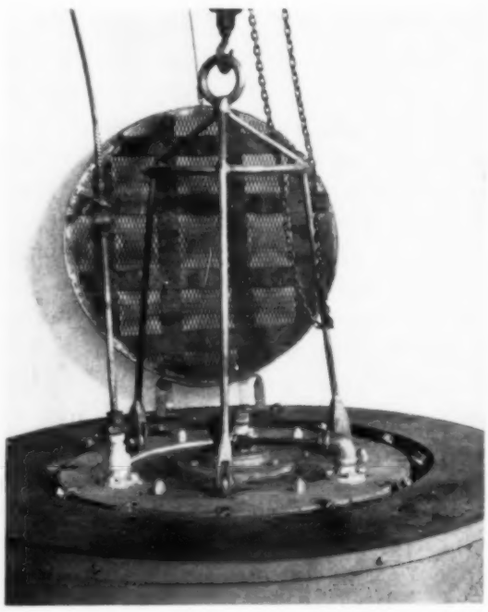
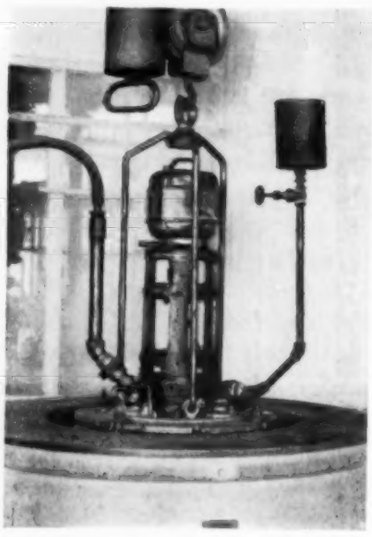


Fig. 1 (Right) — Large Hevi Duty Furnace (Without Atmosphere Circulation Fan) Which Decarburized Steel in Methanol Atmospheres. Fig. 2 (below) is smaller furnace that produced neutral atmosphere from the methanol



From these facts it was believed that the cracking temperature was the principal factor in determining the nature of the atmosphere, whether carburizing or decarburizing.

To check this hypothesis, a special cracking unit was installed in a separate furnace where the cracking temperature could be accurately measured and controlled. The test equipment is shown in Fig. 3. This cracking unit was nothing but a small retort or pot whose tightly fitting lid had three openings — one for a pyrometer,

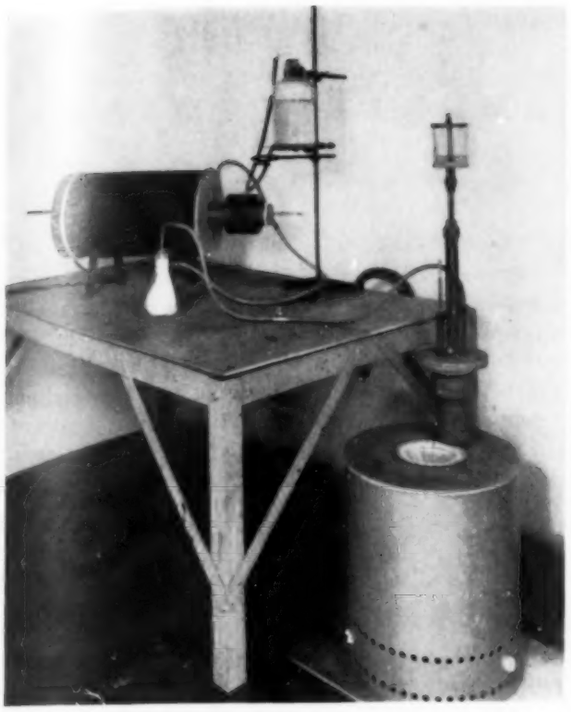


Fig. 3 — Test Unit Where Methanol Could Be Cracked at Known Temperature (Right) and the Resulting Gas Used for Atmosphere in Tube Furnace on Table

another for the entrance of liquid methanol, and the third for the exit of the volatilized products. The retort could be lowered into a heated tube furnace, adjusted so the methanol supply tube was exactly vertical, and remain quiescent until the temperature reached that desired for the test and remained steady. Thereupon methanol was dripped in through a sight oiler, borrowed from the engine room. Cracked gas was led through glass wool and then into the test furnace containing steel samples, gradually replacing the air. Thereupon the temperature in the test furnace was raised to heat treating temperature for the desired period, then cooled and the steel articles removed and their surface conditions determined. The metal parts of this test unit were also of the NC-4 alloy (35% Ni, 15% Cr).

It was found by operating this test unit at various temperatures that methanol began to crack below 500° F., but a condenser in the discharge line of the unit indicated that the cracking (or change to gases whose boiling points were below tap water temperature) was not complete below about 1400° F. Analysis of the gas evolved showed the following range of composition:

H	43.1 to 66.5%
CH_4	28.9 to 2.5%
CO	6.2 to 32.5%
CO_2	19.1 to 0.15%

No determination of moisture was made, but the condenser (not shown in Fig. 2) held at 32° F. would have maintained a dew point of not over 40 to 42° F. if any water had been formed. With such a wide variation in the composition of the atmospheres produced by cracking methanol at various temperatures between 500 and 1400° F. the corresponding variation in the results of using such atmospheres is readily understood.

A few of the atmospheres created in this cracking unit operating at definite temperatures were then used for heat treating atmospheres in a laboratory tube furnace. The heating compartment in this furnace was 3 in. in diameter and 18 in. long; its tube was of NC-4 alloy. Three types of steel were used: S.A.E. 1015, a carbon toolsteel with 0.75% carbon, and an alloy die casting die steel with 0.35% carbon. In all tests all samples remained scale free, but were slightly stained or discolored. This finish, though satisfactory for tools and dies, would not be a truly bright hardening for parts where appearance is an important factor.

The effect of these atmospheres on the carbon content was much more variable than this non-scaling effect. When held 16 hr. at 1820° F. in methanol cracked at 1820° F., all three steels were badly decarburized. The depth of the decarburized area on the die steel was about 0.063 in.; step tests for carbon ranged from 0.07% for the first 0.005 in. to 0.30% at 0.040 to 0.045 in. with 0.36% at the center of the piece. Carbon analyses were not carried to the full depth of the decarburized area; the depth was measured microscopically and a change of about 0.02% carbon is readily observed.

When the cracking temperature was dropped to 1550° F. and the specimens held for 36 hr. at 1820° F., the toolsteel was decarburized while the die steel and the S.A.E. 1015 were carburized. The carbon content at the surface of all three pieces was estimated at 0.40 to 0.50%. (While a carbon *difference* of 0.02% may be visible microscopically, the actual carbon *content* cannot be estimated visually with the same accuracy.)

The atmosphere produced by cracking the methanol at 1590 to 1600° F. proved to be almost balanced (neutral) for the die steel at 1820° F. There was a slight carbon pick-up, but the carburized case as observed in the microscope was only about 0.002 in. deep after 48 hr. at heat. Carburization at this rate would be unnoticeable after normal heat treating periods.

This atmosphere possibly was at equilibrium with austenite containing 0.35 to 0.40% carbon at 1820° F., for the 1015 steel was carburized and the 0.75% carbon toolsteel decarburized in the same heat. However when the heat treating temperature was reduced to 1550° F. the carburizing action of this atmosphere formed at 1600° F. was greatly increased. The carburized surface became about 0.035 in. deep on the die steel. The reason for this is not known. Ordinarily we expect the speed of carburization or decarburization to increase as the temperature is raised, but in a mixed atmosphere containing both carburizing and decarburizing constituents the reaction rate for one may increase more rapidly than for others, or the constituents of the atmosphere may react among themselves at one temperature and not at the other.

Of the many atmospheres available from the cracking of methanol only a few have been tested by us, and these few were tried on only three steels and at two heat treating temperatures. None of these proved balanced to any of the steels at 1550° F. and only one was balanced for one steel at 1820° F. However, these rather limited experiments have demonstrated that with a separate cracking unit in which the cracking conditions could be controlled and duplicated, atmospheres of cracked methanol can be produced in which in one case the surface carbon of a die steel was reduced from 0.36% to 0.07%, in another case a high speed drill rod showed a carbon pick-up of ten points, and in a third case a 0.32% carbon die steel was unchanged after 48 hr. at heat. It seems probable, therefore, that such atmospheres could be adjusted to various steels at their different heat treating temperature, although such adjustment will vary both with the carbon content and the heat treating temperature. In these experiments, the only control necessary was the cracking temperature; fortunately heat treating temperatures can be very accurately measured and easily controlled.

The important conclusion to be drawn from this investigation is the necessity of producing any atmosphere for heat treatment under definitely controlled and readily reproducible conditions. It is doubtful if this can be done in the heat treating furnace itself for, as mentioned earlier, a slight change in the method of admitting the methanol to the heat treating retort changed the atmosphere produced from mildly carburizing to strongly decarburizing.

CAUSTIC EMBRITTLEMENT *

IT IS UNDERSTOOD that all *raw* waters require some chemical conditioning before becoming suitable boiler feed, but one type of water which has heretofore escaped being classified in the unsuitable category is very soft water containing relatively high sodium carbonate. The sodium carbonate is converted to caustic soda by heat and no steel suitable for boiler plate has been discovered which will in itself resist the embrittling effect of caustic.

It has long been known, and has been confirmed by many laboratory tests, that sodium sulphate if present in sufficient quantity serves as a protective agent against sodium hydroxide, and modern boiler practice prescribes the maintenance of a correct ratio of sulphate to hydroxide or carbonate (these two being taken as equivalent) which increases as the working pressure becomes higher. Phosphates have also been recommended, but bad results have sometimes followed. Other salts also retard attack, especially those which are strong oxidizing agents, such as chromates and permanganates. On the other hand, when specimens of steel were tested under stress at temperatures near to 100° C. — that is, in the absence of external pressure — these oxidizing agents actually behaved as accelerators. Several other compounds behaved in the same way.

According to G. T. ATHAVALE there are three types of cracks which may occur in boilers:

1. Corrosion fatigue cracks, resulting from electrochemical processes accelerated by Cl', NO'_3, or SO''_4. They follow the lines of stress without regard to grain boundaries.

2. Ordinary fatigue cracks, caused purely by mechanical stress and following an intracrystalline path.

3. "Brittleness cracks", recognized by their intercrystalline path. These are the result of caustic embrittlement.

Caustic embrittlement requires the simultaneous presence of alkaline liquid and mechanical stress (probably up to the yield point of the steel). The immediate cause is held to be hydrogen absorption. Hydrogen is formed (*Cont. on p. 780*)

*Caustic Embrittlement of Steam Boilers, by W. S. Cazort, Jr., *Refiner & Natural Gasoline Manufacturer*, vol. 19, May 1940, page 156.

Intercrystalline Cracking in Boiler Plates, by C. H. Desch, *The Engineer*, March 31, 1939, page 418.

Caustic Embrittlement of Boiler Plate, *The Metallurgist*, April 28, 1939, page 17.

PLAIN AND ALLOYED IRONS USED IN AUTOMOBILES

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"PRODUCTION of Automotive Castings" was the title of an article in December 1940 METAL PROGRESS, wherein the present writer outlined the metallurgical problems of melting, casting, and heat treating the various classes of gray and malleable iron. Considerable attention was given to piston rings, since their successful production requires an unusual degree of metal, melting and molding control. This second article will discuss other types of irons used in considerable quantity.

Twenty years ago, or even less, the standards of quality for automotive cast iron were not established and knowledge was limited. Since that time much study has been devoted to the subject and, with research and practical experience, considerable knowledge has been obtained in regard to the characteristics of automotive cast irons and their relation to the service record of the casting. This has led to the fixing of standards which have proven their value in a very substantial way. Even so, there still exists quite a divergence of opinion as to the best compositions, alloys and furnace mixtures to be used in any particular casting. The explanation is that there is more than one way to arrive at the same point.

The irons used in automotive castings may be grouped into not less than six general classifications. The requirements for many castings are so similar that naturally the classes are often rather closely related. Each may possess a multitude of minor modifications. As the practices and conditions in each automobile plant and foundry are different, so also are the classifications. However, the following groups may be mentioned:

1. Cylinder iron.
2. Small parts iron.
3. Heat and growth resisting iron.
4. High test gray iron.
5. Piston ring iron (discussed in the article last December).
6. Miscellaneous borderline compositions, such as used in camshafts, cylinder liners, valve seat inserts and crankshafts.

1. *Cylinder iron* is a close fractured gray iron, usually alloyed with chromium, nickel or molybdenum, or combinations of these metals. It is constituted to give a hardness of 185 to 210 Brinell in the bore. Composition is usually held within the following limits: Total carbon 3.10 to 3.40%; graphitic carbon 2.50 to 2.80%; combined carbon 0.50 to 0.70%; silicon 1.80 to 2.40%; manganese 0.50 to 0.80%; phosphorus 0.12 to 0.20%; sulphur 0.10 to 0.12%; chromium 0.10 to 0.50%; nickel 0.25 to 1.50%; molybdenum 0.10 to 0.70%. The tensile strength runs from 35,000 to 40,000 psi. Twenty to 50% of steel scrap is usually added in cupola mixtures. Foundry cokes with tendencies to lower carbon pick-up are preferable, and chill depths are confined to ¼ to ⅜ in. Compositions similar to the above prevent annealing of the bores and valve seats, have a completely pearlitic structure and possess excellent wearing qualities.

Castings of the following nature are generally poured from cylinder iron: Cylinder blocks, cylinder heads, brake drums, cylinder

liners, clutch plates and flywheels. Its chief characteristics are good wearing qualities, streagth, resistance to cracking, close fracture to prevent leaking and provide long wear, uniform hardness, and freedom from segregation.

2. *Small parts iron* has a slightly more open fracture than cylinder iron when compared in the same cross section; the composition is higher in carbon, silicon and phosphorus. The carbon is usually held within the limits of 3.40 to 3.65%; silicon 2.35 to 2.55%; manganese 0.50 to 0.80%; phosphorus 0.25 to 0.40%; sulphur 0.08 to 0.12%; nickel 0.25 to 2.00%. This iron has a Brinell hardness of 150 to 175. The composition is very close to that of the eutectic with silicon of the amount generally present. The structural constituent is principally pearlite, and free ferrite is often present in locations which are subjected to annealing conditions during cooling after casting. It has a tensile strength of 28,000 to 34,000 psi.

Silicon should be held as low as possible to avoid shrink cavities. The cupola mixture usually contains about 10 to 15% of steel scrap, and a coke with fairly high pick-up should be used in melting. Chill depths are limited to from $\frac{1}{16}$ to $\frac{1}{8}$ in. This iron should possess excellent fluidity in order to flow freely in thin sections, and it should also be readily machinable. Many of the castings are annealed and this iron is suitable for parts weighing from a few ounces to 50 lb. Usually poured from this grade of iron are valve stem guides, oil pump bodies, water pump impellers, intake manifolds and transmission case covers.

3. *Heat and growth resisting iron*, as found in automobile, truck and bus service, is similar to cylinder iron, although the total carbon (2.80 to 3.15%) and silicon (1.75 to 2.00%) are usually held somewhat lower, and heavier additions of alloys are used.

Combinations of chromium, nickel and molybdenum similar to the following are often employed: *(a)* Chromium 0.25%, molybdenum 0.75 to 1.25%; or *(b)* chromium 0.50 to 1.00%, nickel 0.75 to 1.50%. The castings are often difficult to machine and are usually annealed at 1400 to 1600° F., whereupon the hardness is 200 to 215 Brinell.

For exceptionally severe conditions, special compositions containing much higher percentages of chromium, nickel and copper are used. One of these contains about 14% of nickel, 5% of copper and 2% of chromium, with 2.60 to 3.00% carbon and 1.25 to 2.00% silicon. This iron is melted in the cupola with special charges, when the higher carbon is acceptable, and does not necessarily have to be annealed. For the lower carbon ranges electric or other types of furnaces are used. When annealing is necessary, temperatures of 1400 to 1650° F. are usually sufficient.

A second composition contains about 24% of chromium and 1.50% of carbon. As cast, this iron has a hardness of 400 Brinell. It must be annealed at a temperature of 1700° F. for eight hours and cooled slowly in the furnace down to 1100° F. After annealing, the hardness is reduced to 280 to 300 Brinell. This low carbon composition cannot be made in the cupola.

Exhaust manifolds, cylinder blocks and liners, truck and bus brake drums, valve seat inserts, diesel engine parts, are often made from compositions similar to the above.

4. *High test gray iron*, as the name implies, possesses greater strength and impact values than cylinder iron by holding carbon lower and silicon generally higher. Compositions cover quite a wide range: 2.00 to 3.00% carbon, 2.25 to 3.00% silicon, sulphur and phosphorus as low as possible, and 0.75 to 1.00% manganese. Alloys are often added when the highest strength and impact values are required. The cupola is usually used when carbon ranges of 2.85 to 3.00 are specified, with high percentages of steel scrap. Nickel in amounts of 0.75 to 1.50% and molybdenum of 0.50 to 1.00% are often added, and chromium in smaller amounts (0.10 to 0.20%).

Tensile strengths of these irons vary from 50,000 to 100,000 psi., depending on the composition, alloys added, and raw materials used, as well as the skill and knowledge put into the melting practice. Impact values are often more than double that for cylinder iron. This iron has a maximum modulus of elasticity of 22,000,000 (two-thirds that of steel), and a higher damping capacity than steel. Its elastic limit in both tensile and torsional test is very high and compares favorably with those of S.A.E. 1045 steel. One notable feature of this iron is the uniformly fine fracture and hardness throughout large cross sections.

So far, high test iron has not found wide use in the automotive field, although it is being used in crankshafts for trucks and diesel engines, and in large dies. Crankshafts weighing 1000 lb. and more are being cast on a production basis, and are proving very satisfactory.

In one foundry, high test gray iron crank-

Fig. 1 — Uniform Hardness of 2¾-In. Test Bar Attached to Crankshaft. Analysis: Combined carbon 0.71%, graphitic carbon 1.90%, silicon 2.26%, manganese 0.81%, phosphorus 0.09%, sulphur 0.052%, chromium 0.02%, nickel 1.07%, molybdenum 0.99%. Strength of 100,000 psi. determined on 0.80-in. bar cut axially (supposedly the weakest portion)

shafts are poured from electric furnaces using the cold charging method. Great care is used in the selection of pig iron and other raw materials. In this particular grade of iron, the total content of sulphur and phosphorus is held below 0.06%. A strict schedule is observed in all details of the melting practice, in the additions of alloys, current and voltage factors, and tapping temperatures. Brinell hardness is confined to limits of 260 to 290, and composition is adjusted for the various sizes of shafts to be poured. This iron requires no heat treatment.

6. *High silicon carbon and graphitic steels* — The only justification for including such compositions, for they are in no sense gray cast irons, is that they are being produced in automotive gray iron foundries.

High silicon, high carbon cast steel has come into wide use during the past few years, and no doubt will continue to increase in favor. It has many of the physical characteristics of spring steel, and in the molten state has to be handled in about the same manner. As cast, it is hard and brittle and must be annealed for four to eight hours. There is no set standard as to the composition and heat treatment; numerous modifications may be followed with corresponding variations in physical properties. The following composition has been used extensively: Carbon 1.20 to 1.45%, silicon 0.80 to 1.30%, manganese 0.60 to 0.75%, phosphorus below 0.10%, sulphur below 0.07%, molybdenum 0.20%. Heat treatment consists of heating to 1575 to 1600° F. and holding for four hours, air quenching to below 1400°, reheating to above 1400° and cooling at not more than 75° per hr. down to 1100° F. This iron has a tensile strength of 120,000 to 130,000 psi., Young's modulus of 30,000,000 to 33,000,000, elongation of 6 to 8%, and a hardness of 225 to 245 Brinell. The structural constituents are spheroidal pearlite and a small amount of pro-eutectoid cementite. With certain modifications in composition and heat treatment, the pro-eutectoid cementite may be disintegrated into graphite.

Certain compositions of these high silicon, carbon cast steels, containing from 1 to 2% copper, show a black fracture after a short anneal, due to the deposition of graphite from pro-eutectic cementite. These are sometimes referred to as "graphitic steels".

These irons cannot be melted in the cupola alone on account of the low carbon requirement. One very interesting set-up is a combination of cupola, converter and electric furnace. By means of this arrangement, continuous melting is attained with a minimum first cost in melting equipment. The iron is first melted in the cupola as gray iron of suitable composition. A weighed amount of this iron is tapped from the cupola and introduced into the converter, and during the time consumed in blowing, deoxidation and addition of alloys, another tap of gray iron from the cupola is weighed into a mixing ladle. The finished converter heat is now added to the mixing ladle; the converter blow has raised the temperature of that metal to about 3000° F. and the combination of the converter and cupola metal has been so balanced that the composition is almost identical to that finally required. The whole is then added to the electric furnace for superheating. The electric furnace is kept well filled at all times and, as the metal added to the electric furnace from the mixing ladle is practically the same in composition as that in the electric furnace, no delay is caused in the continuous pouring of metal to the molding conveyors. This operation obviously requires close metallurgical control. Tapping temperatures are from 2900 to 3000° F.

These compositions are used in crankshafts, brake drums and pistons. It is very likely that its use will be extended to many other automotive parts.

A Few Special Applications

Camshafts — The cast iron automotive camshaft made its appearance a few years ago, and is now used in large numbers. Several com-

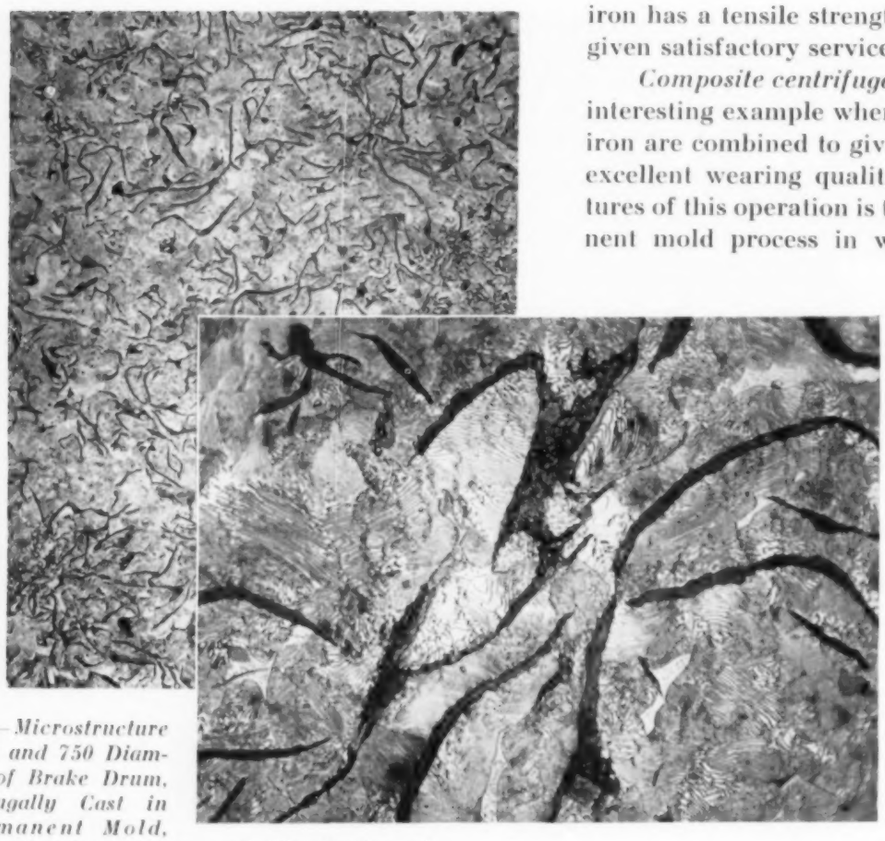


Fig. 2 — Microstructure (at 100 and 750 Diameters) of Brake Drum, Centrifugally Cast in a Permanent Mold, Showing Desirable Form and Distribution of Graphitic Flakes in a Pearlitic Ground-Mass

positions of iron are in production, many consisting of a normal gray iron base. One producer is using a pearlitic malleable iron. One of the first cast irons to be introduced and finding wide application has the following composition: Total carbon 3.25%, silicon 2.25%, chromium 1.00%, molybdenum 0.50%, nickel 0.30%, phosphorus 0.20% and sulphur 0.10%. Hardness of this shaft is held within limits of 250 to 300 Brinell in the body and gear. The structure is principally pearlitic with appreciable amounts of cementite. Cams are hardened to a minimum of Rockwell C-50 by a localized heat treatment. The dissipation of heat from the cam to the body of the shaft is sufficiently rapid to harden the cam. Cams are cast to a very close limit in size, and require a minimum amount of machining and grinding.

The melting practice followed is known as electric furnace duplexing, in which the alloyed base metal is melted in a cupola and finished in the electric furnace. The process is continuous, and a very close chemical and physical control is practiced. Chill test and Brinell hardness test samples are taken at frequent intervals, as well as spectroscopic and chemical tests. This iron has a tensile strength of over 50,000 psi. and has given satisfactory service.

Composite centrifugal brake drums present a very interesting example where the merits of steel and cast iron are combined to give a strong, durable casting of excellent wearing qualities. One of the unique features of this operation is that it may be called a permanent mold process in which the mold becomes an integral part of the casting. A steel stamping, which is the mold and ultimately becomes the outer rim of the drum, is heated by electrical induction to approximately 1600° F., quickly placed in the chucks of a centrifugal machine and rotation started. In the meantime a weighed amount of duplexed electric furnace iron is poured into an attached runner basin, and the molten iron introduced into the red-hot revolving steel stamping. A perfect fusion is formed between the steel and iron surfaces. The result is a drum with a strong reinforced backing of mild steel combined with a rigid, excellent braking surface of cast iron. Micro-examination of the zone of fusion between steel and iron reveals a deep penetration of carbon from the cast iron into the steel, forming lamellar pearlite.

The composition of iron found to be most suitable from the standpoint of machinability and wear, and which was adopted for this drum, was a high carbon, moderately low silicon iron: Carbon 3.60 to 3.70%; silicon 1.90 to 2.00%; chromium 0.15 to 0.25%. Its fracture is gray and extremely fine. The structure is lamellar pearlite. An interesting feature of this operation is the formation of slag on the inner surface of the iron during the spinning and solidification, containing a large amount of sulphur and manganese forced from the iron by the pressure of centrifugal action.

Cylinder liners use quite a variety of iron compositions, although the majority are similar to cylinder iron but harder, with somewhat lower carbon and silicon. The following composition is fairly representative: Total carbon 3.10 to 3.25%; combined carbon 0.60 to 0.75%; silicon 2.00 to 2.20%; manganese 0.60 to 0.80%;

phosphorus 0.25% max.; sulphur 0.12% max.; nickel 0.50 to 1.50%; chromium 0.30 to 1.00%; molybdenum 0.40 to 0.70%. Special compositions are also used (as mentioned under heat and growth resistance compositions) where extremely severe conditions are encountered.

Heat treated cylinder liners are in high favor and have the advantage of greater hardness over the "as cast" liner. The liner to be heat treated is annealed, which makes it readily machinable; after machining it is heated to 1500° F. or higher in a neutral atmosphere and quenched; it is then tempered at from 400 to 700° F. depending on the hardness desired, and ground to size. This process also is probably the best for removing all internal strains.

The symmetrical shape lends itself admirably to centrifugal casting, and large numbers are being produced in this manner, in sand or permanent molds. It is usually necessary to anneal the latter.

Nitrided liners are also being produced. The base iron is similar to that used in other sleeves. The composition, however includes the alloying metals aluminum, chromium and molybdenum in amounts of about 1.00% each. Vanadium may also be present. The liners must be heat treated and machined before nitriding, and ground to size as a final operation.

Pistons, as a general rule, are produced from cylinder iron. Those which are subject to heavier duty and to more severe heat conditions are sometimes made from heat resisting irons. Quick anneal, high silicon-carbon or graphitic steel pistons are also being produced with considerable success. The great strength and toughness of this metal in annealed castings permits machining to such thin sections that they are comparable with aluminum pistons in weight, with the advantage of a much smaller coefficient of expansion.

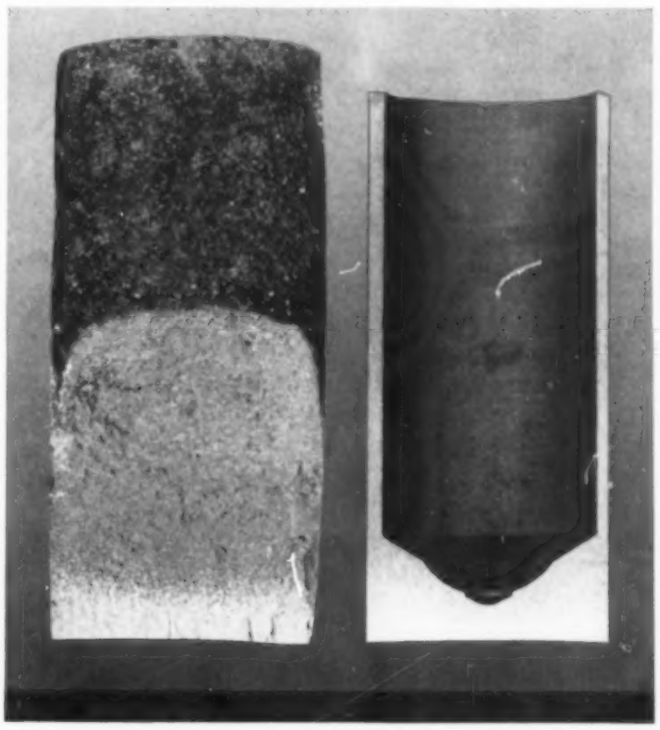
Valve seat inserts — Valve seats, especially on trucks and busses, are often severely overheated, and valve seat inserts have been devised of special compositions to withstand the service.

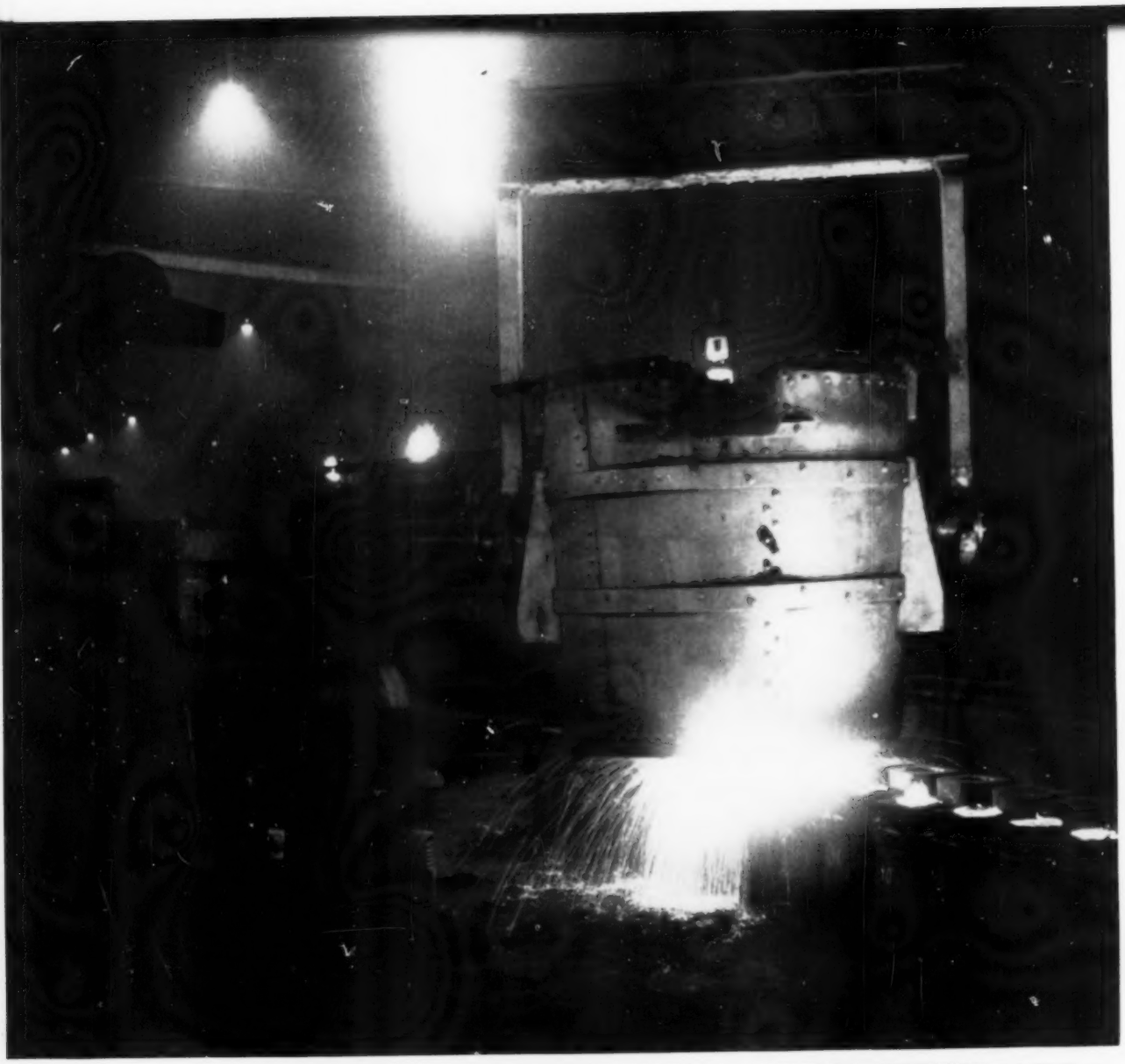
Several alloys such as stellite, high speed steel and alloyed cast iron have been used with success. Cast iron inserts may be made of cylinder iron with addition of about 1.50% of chromium; molybdenum is also used in varying amounts from 0.5 to 5%. Many of the other compositions of highly alloyed iron should also prove be very suitable.

The foundry practice employed is similar to that in the molding of piston rings. The use of permanent molds is also an ideal set-up for their production. The iron is white in fracture with a hardness of more than 500 Brinell. Alloys are added to prevent cracking, growth and softening; molybdenum is especially valuable on account of its strengthening effects at high temperatures. The inserts must be ground as they are too hard to machine.

Tappets of chilled cast iron are also being produced in large quantities by a number of automobile foundries. Several different methods are used in casting. One includes the use of sand cores and standard molding sand casting practice, another uses cores and a permanent mold, while in a third foundry the standard molding sand practice is followed but the cores are eliminated, the tappet cast solid and drilled out. This last method is economical, and the tappets show a fine service record. The chilled cam-contact face, after grinding, receives an oxidizing treatment that improves the wearing life of the cam and eliminates scoring. The structure of this tappet is shown below.

Fig. 3 — Cast Iron Tappet, as Cast, Broken at End to Show Chill. Solid bar is drilled and finished outside. Finished tappet is cut along axis to show internal form and relation to chilled end. (About 50% oversize)





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TOPPING STEEL INGOTS

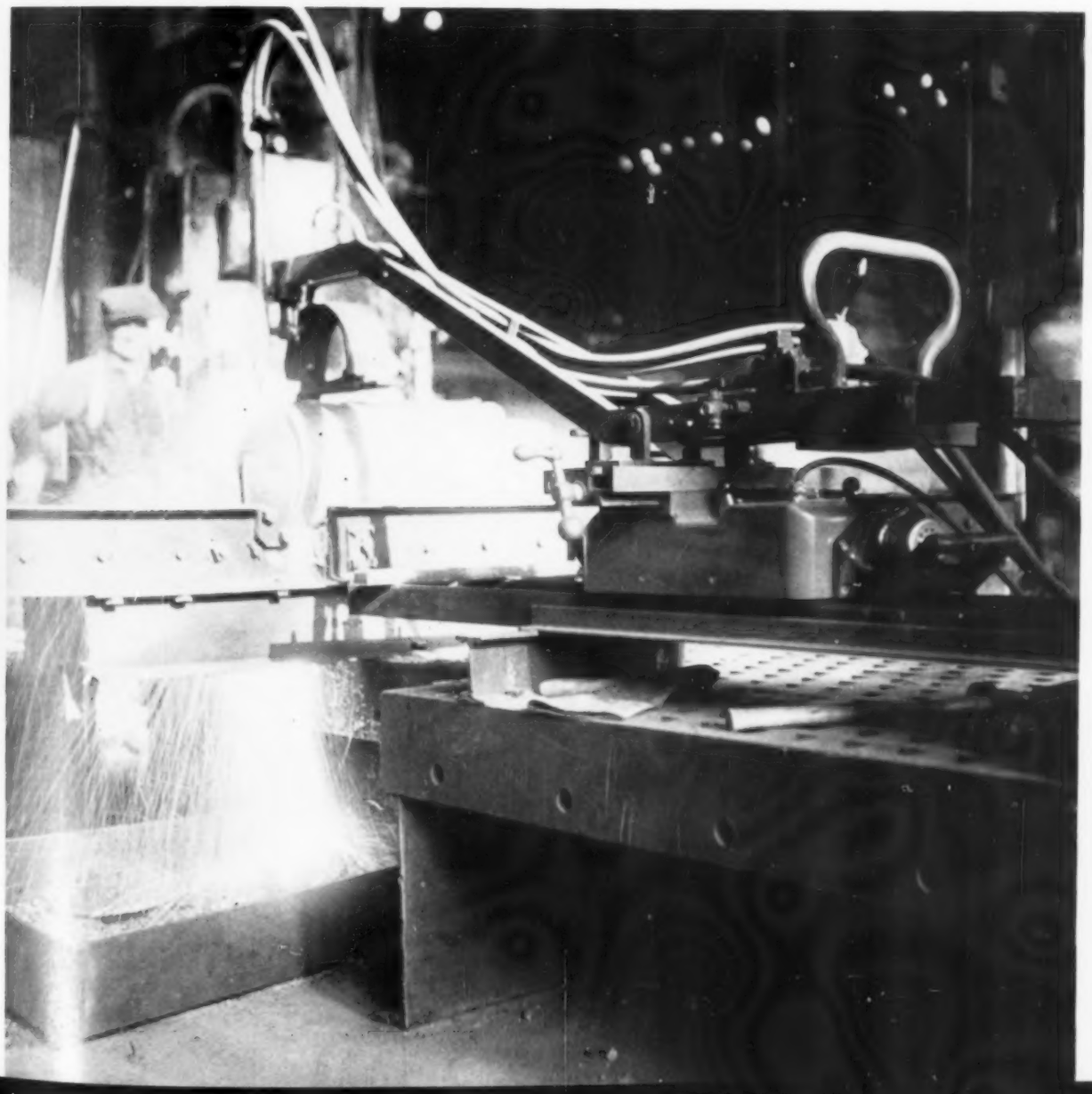
for large shell forgings

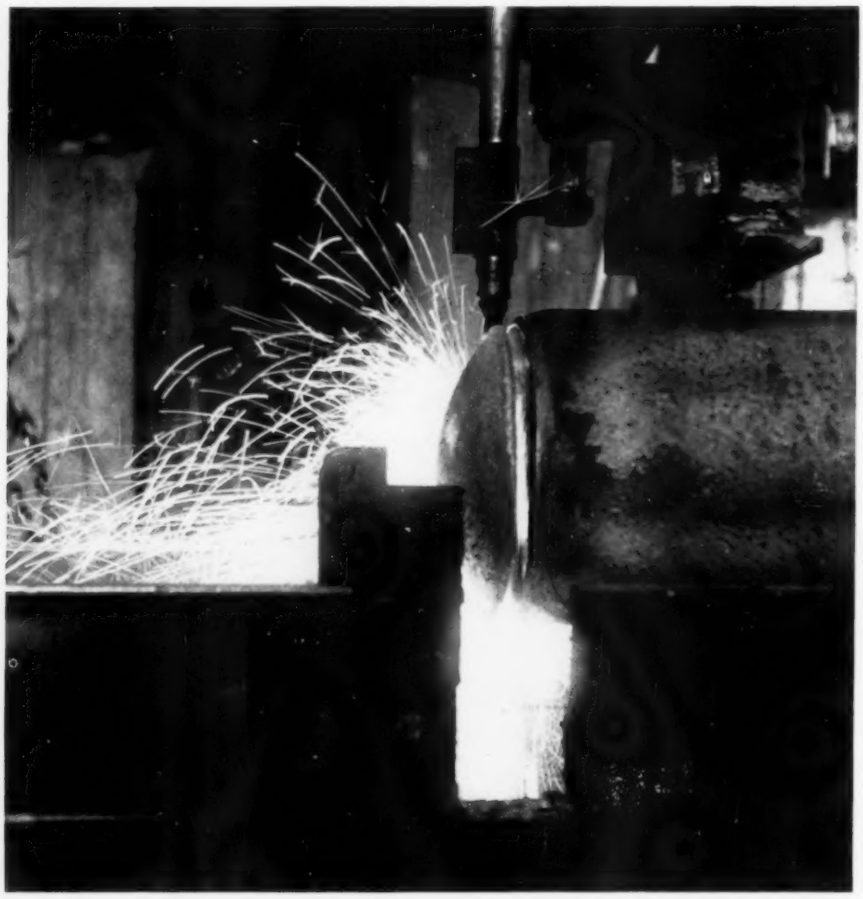
THE ACCOMPANYING photographs were taken in a Canadian plant currently engaged in the large-scale production of shells. They illustrate some interesting steps taken in the preparation of steel ingots prior to forging a 9.2-in. shell. Two oxy-acetylene cuts are taken soon after stripping and while the ingots are still hot; one trims the bottom and the second slices off the top. The photographs were furnished through courtesy of The Linde Air Products Co.

(Left) Ca[illegible]n steel (0.50% C) is poured int[illegible] individual molds, each of which hol[illegible] enough metal for one 9.2-in. she[illegible]rging. Ingots are 12 in. square, w[illegible] domed bottom, corrugated sid[illegible] and a sink head top.

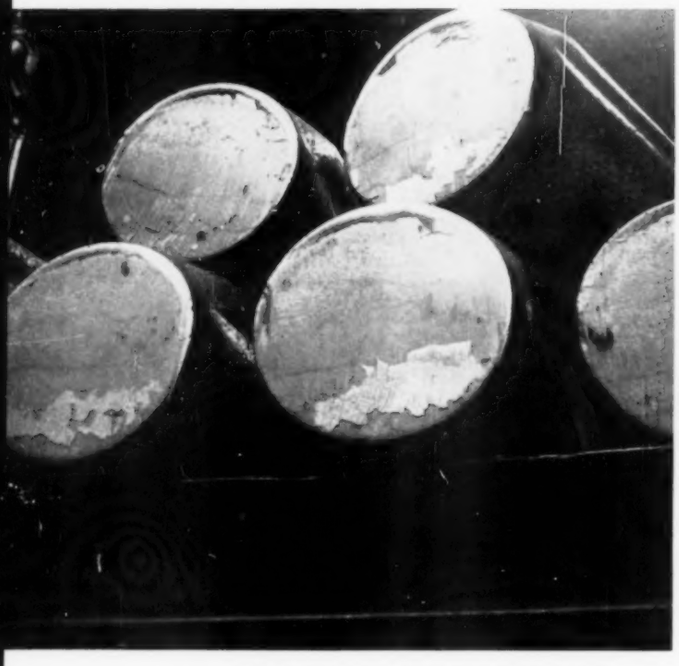
(Below, left) After the steel has solidified, the ingot is removed from the mold. Its temperature is about 1700° F. It is then allowed to cool for a short time before it delivered to the cut-off machines, where bottom cut is started immediately.

(Below) The hot ingot is moved into position on a roller conveyor where an automatic oxy-acetylene cut-off machine squares up the bottom. The overhanging arm holding the cutting blowpipe is hinged at its carriage, and as the machine advances, a roller on the extreme end of the arm rides over a curved track, allowing the blowpipe to follow the contour at the bottom of the ingot.

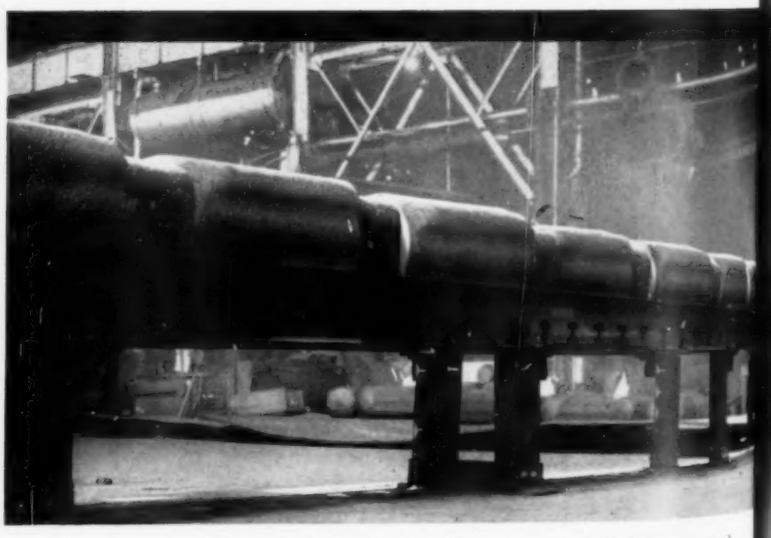




Close-up of first cutting operation. The notched channel in the central foreground supports the stop bar and rollers for aligning the ingot. When the cut is completed, the ingot will pass on to the next cutting operation. The curved guide track for keeping the cutting tip at the correct elevation (shown in the upper right-hand corner of the picture) is high enough to clear the ingot.

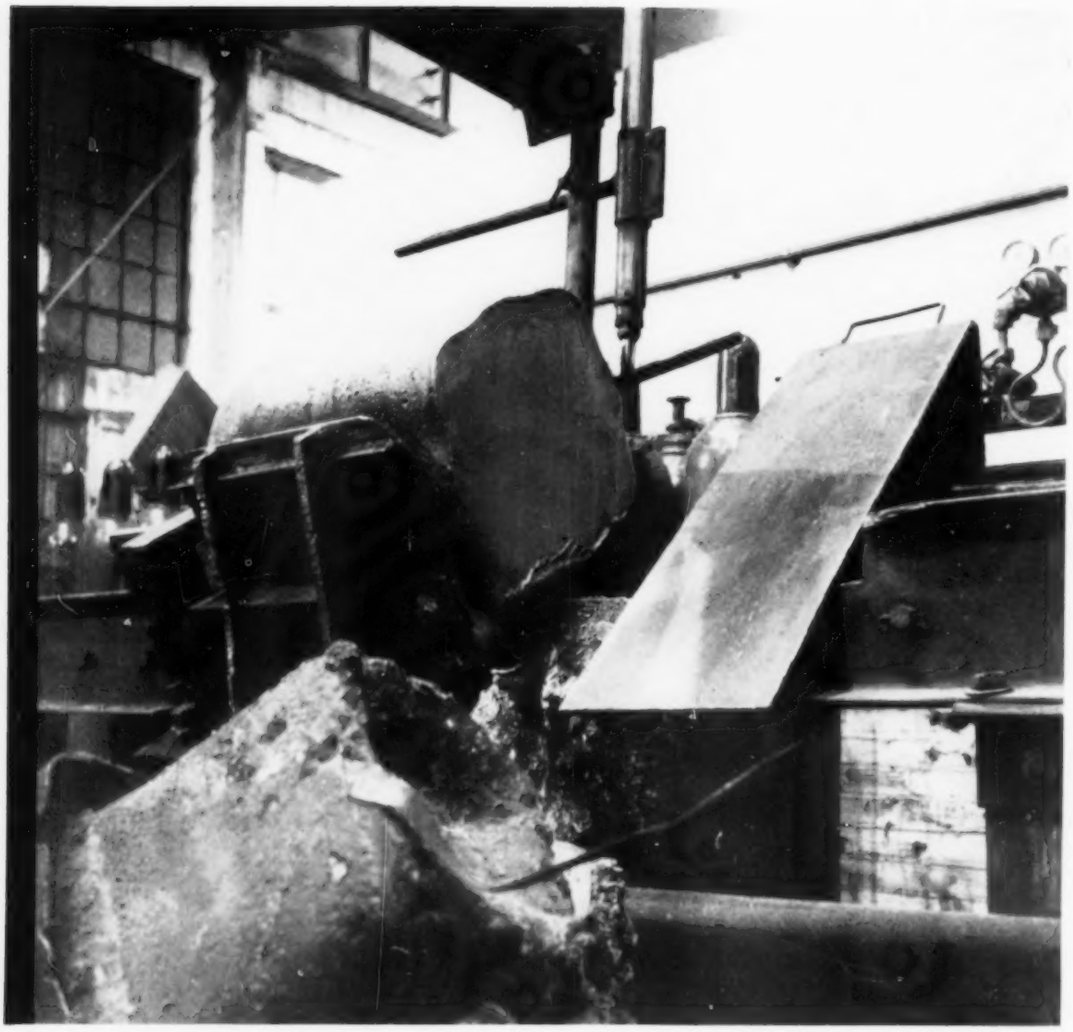


This group of ingots shows the quality of cuts obtained in the bottom cropping operation, and also reveals perfectly sound metal. Each of these cuts requires 23 cu.ft. of oxygen and is completed in 86 sec.



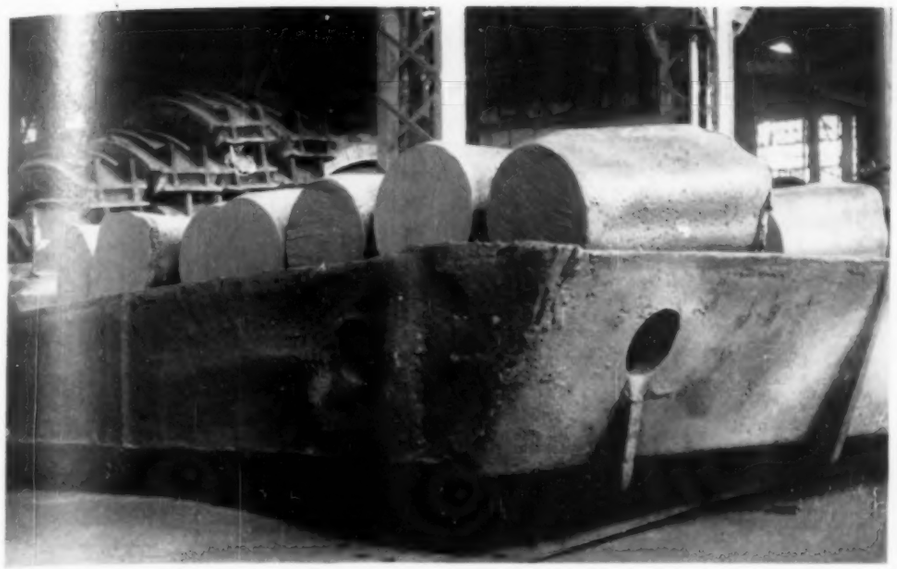
After the ingot is bottom cropped it is conveyed to a second cut-off machine where the sink head is topped. The temperature of the steel during this second cut is still between 1100 and 1250° F.

The cut-off machine used for the second cutting operation is slightly different in design from the first; it has a follower roller that rides the ingot surface, following the corrugations as the blowpipe moves forward, thus keeping the cutting nozzle the proper distance from the work regardless of surface contour. When the ingot is in position for the second cutting operation it is tilted at an angle of approximately 30° to facilitate starting the cut and to insure clean finishes. This short movable section of the conveyor is tilted by an air cylinder; ingots are therefore rapidly loaded and unloaded. The time required for the second cut is 2 min. 30 sec., and the oxygen consumption is 35 cu.ft.

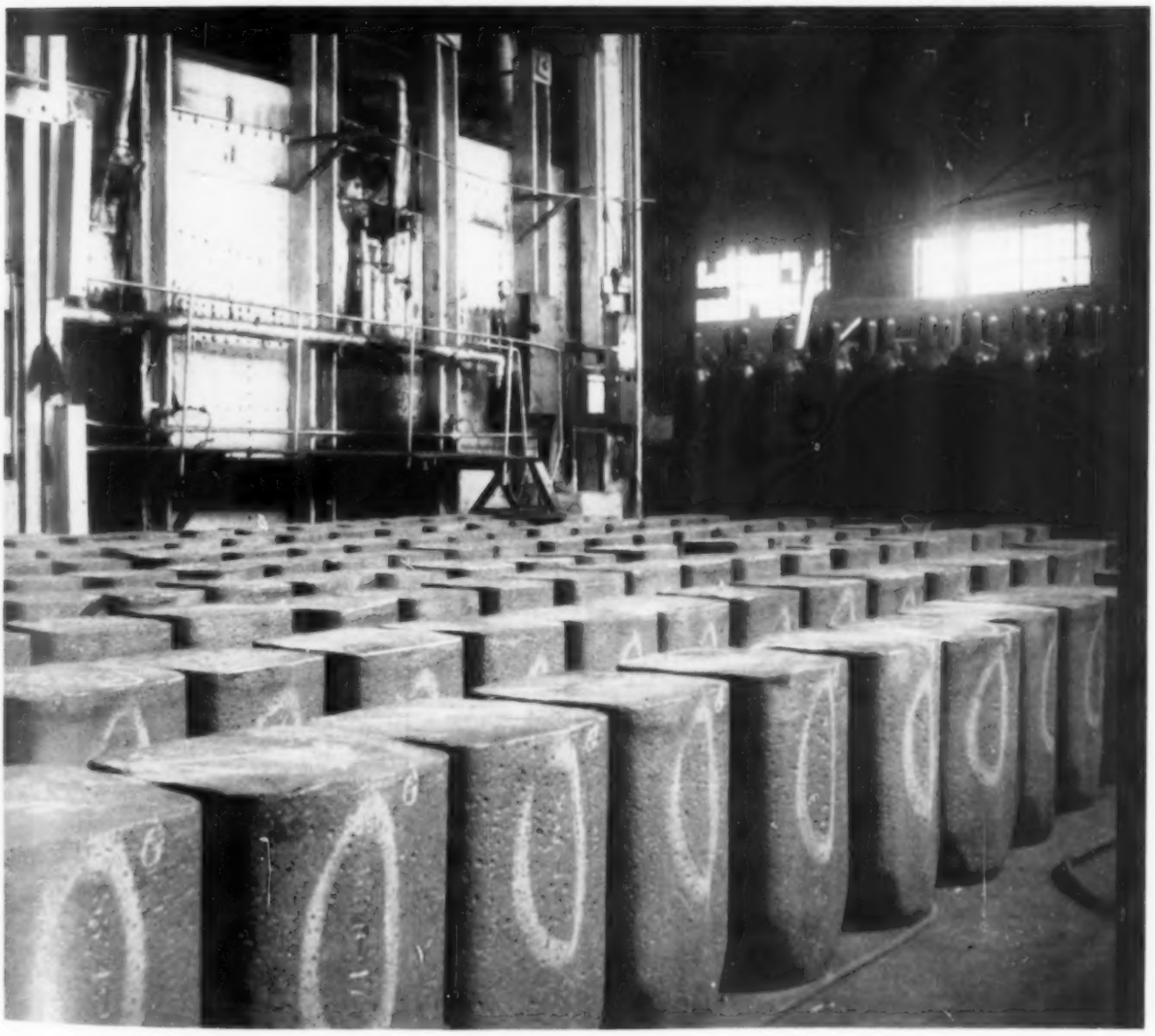


Close-up, just after topping cut is finished. The discard slides down a skid plate into a scrap boat and is returned to the steel furnaces to be remelted.

Ingots are placed in warm sand immediately after the last of the two cutting operations. This retards cooling and is a precaution against surface cracking on this rather hard steel.



Cold castings are piled in steel boxes and delivered to the cleaning department where the slag and rough edges are removed prior to shipping to the forge shop. Ingots do not need to be sandblasted on their sides.



Rows of finished castings ranked like good soldiers. Inspected and passed, they are ready for forging into ammunition for naval and coast defense guns. Whitewash circles indicate the location of identifying numbers.

NAVY SPECIFICATIONS AND INSPECTION

By B. K. Culver*
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THE OBVIOUS PURPOSE of the general specifications of the U. S. Navy is to obtain uniformity of material and workmanship throughout the vessels of the United States. Less obviously, they incorporate the results of experience in regard to special requirements of naval design, to the end that all interested may more fully cooperate in the production of efficient fighting vessels.

All the usual desirable characteristics of commercial machines are equally important from the naval point of view. Certain additional characteristics, which commercial service does not ordinarily require, are extremely important to the U. S. Navy, such as

1. Maximum reliability.
2. Minimum space and weight.
3. Maximum accessibility for inspection, maintenance, and repair.
4. Maximum resistance to corrosive action and, in particular, moist sea air and salt water.
5. Economical operation and maintenance.
6. Satisfactory operation when inclined
   (a) Up to 15° either side (permanently)
   (b) Up to 45° rolling and a pitch of 10° up and down.
7. Satisfactory operation under the large uneven stresses induced by the laboring of a vessel in a seaway and at variable propeller loads.
8. Satisfactory operation even though the mountings vibrate at fairly high frequency.
9. Satisfactory operation under heavy shock to mounting and structure.
10. Maximum interchangeability of parts.
11. Ready susceptibility to repair by Naval personnel and with facilities found at sea.

These requirements are no recent discovery. The Naval Inspection Service had its inception in the first naval shipbuilding program when the construction of six frigates was authorized by the Congress of 1794. This group included the historic "Constitution", which was constructed under Contract No. 1. Ship captains and other officers were then appointed to inspect ship construction, shipbuilding materials, naval ordnance accessories, equipment and naval stores.

Since that modest beginning, this service has continued to function and has progressed with the changes from wooden hulls to steel hulls, from sails to modern steam turbines, oil engines and electric motors of high power. It has made notable contributions to practically all branches of private industry and to the advancement of the naval sciences in general. ANDREW CARNEGIE gave the U. S. Navy credit for improving and stimulating the great steel industry.

It is probably one of the oldest and most extensively organized inspection services of the various Government departments. The Navy originated and developed most of the early important hull and machinery designs, and specified the present modern ones which were developed by the various shipyard contractors in collaboration with the Navy Department.

For that force — commonly known as Field Inspection at the manufacturing sources — the Department has divided the United States geographically into 12 Naval Inspection Districts with inspection headquarters located in the industrial centers where much inspection will be done. For purposes of economy and to render prompt service, branch inspection officers

*A talk before the Minneapolis Chapter, Feb. 6, 1941, based on an article by Capt. R. C. Davis, U.S.N. (retired) in *Journal* American Society of Naval Engineers, Feb. 1939, entitled "The Naval Inspection Service". This article is not to be construed as an official statement by the U. S. Navy.

American Cruisers Rounding Cape Horn in a Storm, April 1938

Copyright Movietone News; Courtesy U. S. Navy Intelligence

with resident inspectors in charge are established in other industrial centers within the same district. These, as a rule, are under the command and are administered by a commissioned officer who has acquired technical knowledge through education and experience in the operation and maintenance of machinery on shipboard, construction of new ships, or repair of ships in the fleet or at the Navy Yards. Several assistant inspectors, qualified for their appointments by reason of their technical education or manufacturing experience and familiarity with the inspection and testing of materials, mill practices, shop processes and production methods, are assigned to these offices.

The civilian assistants take great pride in their work and are as loyal to their oath and to the Navy as any Government official. Their anchor stamp placed upon material inspected and accepted by them represents their word of honor, in which the Navy may place the highest confidence. Their efficiency is very high and their errors in judgment are indeed rare. Practically all major material and workmanship defects are discovered during field inspection or during the shop and laboratory tests. Many of these would not be noticed at destination. They would, however, appear during the subsequent operation of the ship, and would be referred back to the contractor as his responsibility.

In contracts for materials, machinery and supplies written by the U. S. Navy, there is a clause which provides that the contractor is responsible for the satisfactory operation in service. This responsibility usually ends from one to two years following the date of commissioning of the vessel. If any errors in workmanship or fault in material develop, the contractor is required by law to replace this material or equipment at his own expense. Thus the inspector who rigidly tests the materials at the source, and who requires Navy-inspected materials to enter into the construction of the machinery, is a protection to the contractor as well as to the Navy.

The Specification Section in the Bureau of Ships (which is a recent combination of the old Bureaus of Engineering and of Construction and Repair) is composed of several materials engineers and scientists under the command of a commissioned officer whose education and experience qualify him for such duty. Operating directly under this section are the several laboratories and testing stations maintained by the Navy, such as the Naval Experiment Station at Annapolis, Bellview Research Laboratory in Washington, and the Boiler Laboratory in the Philadelphia Yard; also the Material Testing Laboratory at the New York Navy Yard and at Munhall, Pa. This section is continuously examining and testing new and old materials and striving in every way *(Continued on page 768)*

THE CORROSION RESISTANCE OF FREE-MACHINING STAINLESS STEEL

By Stanley P. Watkins
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ALTHOUGH the stainless steels are totally or partially resistant to many highly corrosive media, it is a well recognized fact that they are not sufficiently noble to resist all conditions of exposure, nor can any of them be flatly accorded the designation "non-corrodible" without certain qualifications. The evaluation of a metal's general corrosion resistance is a difficult and complex problem. It usually involves accelerated methods of testing, which at best serve only to indicate resistance to a particular and limited set of conditions. It is a rare case where accelerated laboratory tests will accurately indicate a metal's performance under approximate conditions when it is applied in industry, owing to those slight differences in concentrations, impurities and variations in temperatures invariably encountered.

The capacity to become "passive" is an outstanding property of the stainless steels. The conditions under which this can occur are varied and numerous. A slight change in some condition, such as an increase in temperature, an increase or decrease of oxygen in the surrounding environment, or a change in concentration of a solution in contact, will often throw the metal from a state of passivity to one of activity or vice versa. In general, all stainless steels in the active condition are rapidly corroded, but when passive are either virtually immune or are relatively slowly corroded. The boundary between passivity and activity is narrow, often shifting with minute changes in exposure conditions or minor changes in metal composition.

Proper interpretation of corrosion data on the stainless steels, whether based on accelerated or service exposure, must therefore take into account the ability of these alloys to become passive, else erroneous conclusions may be drawn. In general, oxidizing conditions pro-

Table 1 — Analyses of Stainless Steels Used for Corrosion Tests

GRADE	C	MN	P	S	SI	CR	NI	MO	SE
12% Cr	0.10	0.38	0.019	0.015	0.31	12.30	0.21	..	..
12% Cr-FM	0.11	0.42	0.016	0.33	0.29	12.98	0.19	0.35	..
17% Cr	0.12	0.45	0.022	0.018	0.36	17.09	0.27	..	..
17% Cr-FM	0.08	0.59	0.025	0.30	0.44	16.02	0.71	0.39	..
18-8	0.07	0.39	0.025	0.016	0.41	18.52	8.53	..	..
18-8 S-FM	0.06	0.62	0.024	0.33	0.40	18.25	9.29	0.36	..
18-8 Se-FM	0.05	0.92	0.130	0.010	0.65	18.18	8.53	..	0.28

mote passivity; acidity favors activity of acids which liberate hydrogen.

Resistance of the stainless steels to corrosion is reduced somewhat by the addition of sulphur or selenium for free-machining properties, especially under severe conditions, such as exposure to acid solutions. At any rate, for a majority of industrial applications the free-machining grades serve equally as well as the corresponding regular grades.

Results of a series of laboratory corrosion tests on the various free-machining stainless steels, along with regular grades, are presented in several tables. In studying these data, which include exposure to acetic, hydrochloric and nitric acids, salt spray and tap water, it should be borne in mind that the figures represent greatly accelerated conditions for the most part, and should not be used as the sole criterion for evaluating a particular grade's suitability for service involving much less corrosive conditions. The figures are given merely to indicate the *relative* resistance of the various grades to the reagents used in the tests, and the results obtained can in no way be interpreted to cover dissimilar conditions of exposure. As a matter of fact, many thousands of tons of the free-machining stainless steels are used each year for applications involving exposure to crude oil, gasoline, fruit juices, dairy products, foods, beverages, atmospheric conditions, textile dyes and paper pulp, with complete satisfaction to the user.

Nitric Acid — The regular high chromium and 18-8 grades of stainless steel are highly resistant to nitric acid, which is strongly oxidizing, and are widely used for handling this chemical. On the other hand, the straight chromium grades having less than about 14% chromium, while resistant to HNO_3 solutions at normal temperatures, will generally be corroded at temperatures around the boiling point. Typical corrosion rates for the free-machining stainless steels and the corresponding regular grades, when exposed to 65% boiling nitric acid, are given in Table II. It will be noted that a high sulphur or selenium content in the stainless steels materially reduces their resistance to attack by boiling acid. (These and other experiments were performed by I. C. Clingan.)

Table II — Corrosion in 65% Boiling Nitric Acid
(Figures represent inches penetration per month)

Grade	Condition	Brinell Hardness	First 48 Hr.	Second 48 Hr.	Third 48 Hr.
12% Cr	Hardened	363	0.01830	0.01355	0.06370
12% Cr	Do. and tempered	223	0.01410	0.02051	0.02530
12% Cr-FM	Hardened	387	0.06181	0.09820	0.10120
12% Cr-FM	Do. and tempered	223	0.07599	0.1244	0.1261
17% Cr	Annealed	183	0.00176	0.00182	0.00211
17% Cr-FM	Annealed	192	0.0241	0.0546	0.0595
18-8	Annealed	153	0.000718	0.000642	0.000606
18-8 S-FM	Annealed	156	0.0206	0.0860	0.0910
18-8 Se-FM	Annealed	156	0.0482	0.1368	0.0983

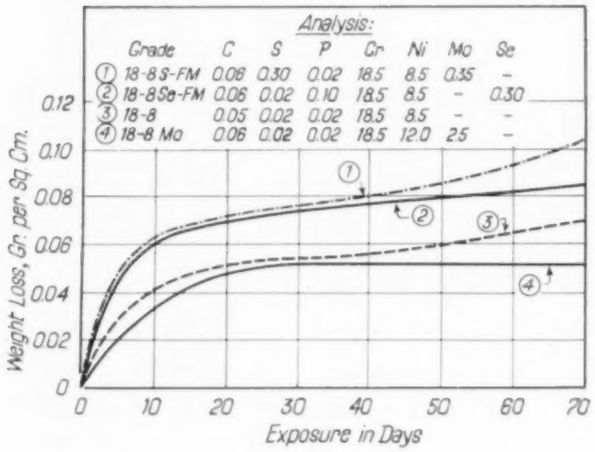
Table III — Hydrochloric Acid Corrosion Test
(0.5% by weight hydrochloric acid at 80° F.; weight loss in g. per sq.in.)

Grade	Condition	Brinell Hardness	First Period	Second Period	Third Period
12% Cr	Hardened	363	0.0130	0.0017	0.0015
12% Cr	Do. and tempered	223	0.0104	0.0011	0.0016
12% Cr-FM	Hardened	387	0.0155	0.0090	0.0120
12% Cr-FM	Do. and tempered	223	0.0130	0.0045	0 0070
17% Cr	Annealed	183	0.0160	0.0097	0.0090
17% Cr-FM	Annealed	192	0.0970	0.1140	0.1600
18-8	Annealed	153	0.0030	0.0010	0.0008
18-8 S-FM	Annealed	156	0.0039	0.0010	0.0009
18-8 Se-FM	Annealed	156	0.0036	0.0015	0.0023

The normal rate in 65% boiling nitric acid for annealed 18-8 averages 0.00070 in. penetration per month, but when sulphur or selenium is added, the corrosion is greatly accelerated and rates above 0.080 in. are not unusual. 18-8 Se-FM, with an average rate of 0.0944 in. penetration per month for three periods, is less resistant than 18-8 S-FM, which averages 0.0660. Resistance of the sulphur-bearing grade to attack by boiling 65% HNO_3 is materially improved by the addition of 0.35 to 0.50% molybdenum. The average rate (three 48-hr. periods) of an alloy containing 0.08% C, 0.33% S, 18% Cr, 9% Ni, and 0.36% Mo, was 0.0640 in. penetration per month, whereas the rate for a similar alloy that

contained no molybdenum was increased to 0.204 in. penetration per month in boiling 65% nitric acid.

It is the opinion of some users that if the mean corrosion rate of a straight chromium stainless steel alloy when exposed for five 48-hr. periods in boiling 65% HNO_3 is less than 0.006 in. penetration per month, it is satisfactory for handling the acid. On this basis it would appear that none of the free-machining stainless steels are suitable for containers for concentrated acid at the boiling point. However, at normal temperatures all the free-machining stainless steels are highly resistant to nitric acid in concentrations above 20%.



Resistance of Free-Machining Grades of 18-8 to Dilute HNO_3-H_2SO_4 Mixture at 70° F. Is Rather Less Than the Regular Grades During the First Two or Three Weeks, But All Grades Then Become Passive Enough so That Subsequent Losses Are Very Small

Hydrochloric Acid — Solutions of hydrochloric acid, as a rule, strongly attack the stainless steels. The corrosive effect of a 0.5% hydrochloric acid solution on the free-machining as well as the corresponding grades of stainless steel is shown in Table III (page 711). It will be noted that the initial rate of attack in the first period drops off on subsequent exposure, indicating the development of some passivity. The exception is the 17% Cr-FM grade. The addition of sulphur materially reduces the resistance of the straight chromium grades, but has slight effect on 18-8. Selenium in the 18-8 alloy apparently tends to reduce resistance more than sulphur, but the difference is not marked. With stronger solutions, coupled with moderately high temperatures, attack by hydrochloric acid is greatly accelerated and the difference between the regular and free-machining grades becomes more marked.

Sulphuric Acid — In general, the stainless steels, particularly the straight chromium grades, are not regarded as satisfactory where service involves exposure to sulphuric acid solutions. In some instances, accelerated attack occurs upon initial exposure which subsequently drops off (or ceases altogether on prolonged exposure) owing to the metal becoming passive. The addition of approximately 3% molybdenum to regular 18-8 stainless steel substantially increases its resistance to sulphuric acid. The passivity range is also greatly extended if an oxidizing chemical, such as nitric acid, copper sulphate or ferric sulphate, is present in the solution in the correct proportions and the temperature is not excessive.

Resistance of four 18-8 grades of stainless steel to a dilute sulphuric-nitric acid solution at room temperature is shown by the diagram at left, forwarded in a private communication from J. L. Patterson of Eastman Kodak Co. The loss, even for the free-machining grades, is negligible and permits their use for handling this mixture. Passivity develops in all the grades after about the first two weeks.

Table IV — Corrosion by Acetic Acid (20% by Weight) at 80° F.

Grade	Condition	Brinell Hardness	Weight Loss *(a)*	Remarks
12% Cr	Hardened	363	0.00060	Slightly pitted
12% Cr	Hardened and tempered	223	0.0120	Badly pitted
12% Cr-FM	Hardened	387	0.00016	Slightly pitted
12% Cr-FM	Hardened and tempered	223	0.0228	Badly pitted
17% Cr	Annealed	183	0.00013	Very slight attack
17% Cr-FM	Annealed	192	0.00016	Very slight attack
18-8	Annealed	153	0.000106	Very slight attack
18-8 S-FM	Annealed	156	0.00013	Very slight attack
18-8 Se-FM	Annealed	156	0.00013	Very slight attack

(a) Grams per sq.in. of exposed metal, after 125 hr.

Acetic Acid — Stainless steels are characteristically passive in acetic acid solutions of all concentrations at room temperature, and this is particularly true of 18-8. Although the straight

chromium grades tend to passivity, they are more likely to corrode. As shown by Table IV the regular grades of stainless steel possess slightly better resistance to a 20% solution of acetic acid than the corresponding free-machining grades.

Salt Spray — One of the most commonly used methods for determining resistance of metal to the atmosphere, moisture, and water or salt water, is the salt spray test. It is not infallible, but if an alloy has any inclination to rust or corrode in normal atmosphere it will be revealed by this test. The salt spray test does not lend itself readily to quantitative measurement; specimens are generally judged by their appearance after exposure. Slight surface rusting or staining is not usually regarded as "failure", but the presence of progressive corrosion

At Left Is Shown Condition of Stainless Steel Specimens Described in Table V, page 714, After 100 Hr. in Salt Spray Cabinet

At Right Is Shown Perfect Resistance of All Specimens (Both Regular and Free-Machining Grades) to 125 Hr. in Tap Water

Table V — Salt Spray Test *(a)*

Grade	Condition	Condition of Specimens During Exposure			Condition of Specimens After Cleaning
		After 18 Hr.	After 48 Hr.	After 100 Hr.	
12% Cr	Hardened	Slightly rusted	Slightly rusted	Badly rusted	Slightly pitted
12% Cr	Hardened and tempered	Slightly rusted	Badly rusted	Badly rusted	Slightly pitted
12% Cr-FM	Hardened	Rusted	Very badly rusted	Very badly rusted	Slightly pitted
12% Cr-FM	Hardened and tempered	Badly rusted	Very badly rusted	Very badly rusted	Very badly pitted
17% Cr	Annealed	OK	OK	OK	Not pitted
17% Cr-FM	Annealed	Slightly rusted	Very badly rusted	Very badly rusted	Very slightly pitted
18-8	Annealed	OK	OK	OK	Not pitted
18-8 S-FM	Annealed	Slightly rusted	Slightly rusted	Slightly rusted	Not pitted
18-8 Se-FM	Annealed	OK	Slightly rusted	Slightly rusted	Not pitted

(a) Specimens finished with 120-grit emery, exposed to 4% NaCl under 10-lb. air pressure.

as evidenced by severe rusting and localized pitting is often considered serious.

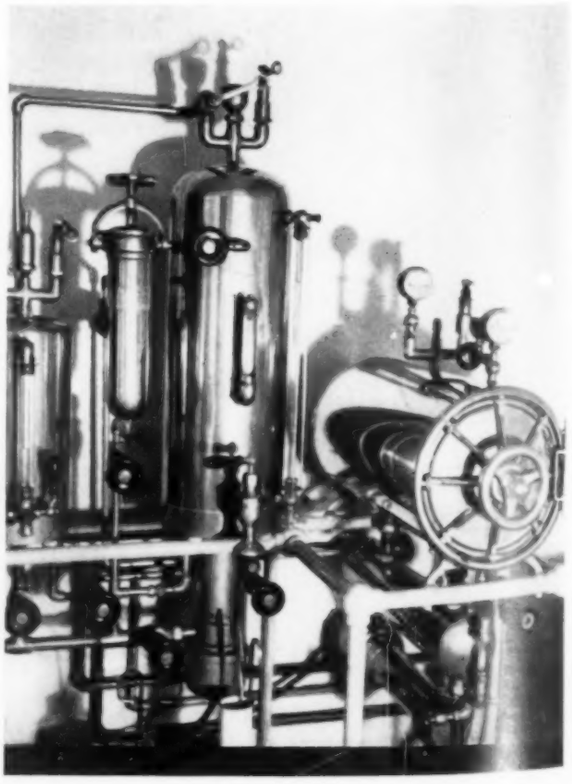
The appearance of free-machining stainless steel specimens, along with the corresponding regular grades, after 100 hr. exposure to the standard salt spray test is shown by the first group of photographs on page 713. A detailed description of these specimens is given in Table V.

It will be noted that each of the free-machining stainless steels rusted to a greater extent than the corresponding regular grade, this being particularly true of the straight chromium alloys. There was very little difference in appearance between the three 18-8 grades, indicating that sulphur or selenium additions to 18-8 do not appreciably lower its resistance to this exposure. In the case of the 12% chromium grades, the hardened specimens showed somewhat better resistance than the ones hardened and tempered, which is typical for these alloys.

Tap Water — The appearance of a group of specimens, identical to those used in the salt spray test, after exposure to running tap water for 125 hr. is shown by the second group of photographs. This test is relatively mild, but will seriously corrode ordinary steel; note that all the specimens resisted perfectly.

Scale Resistance — As shown by the last table, the resistance of the free-machining stainless steels to oxidation at moderately high temperatures is about the same as for the regular grades. However, at 2050° F. the free-machining grades have a tendency to scale considerably more than the regular ones. The only exception is 17% Cr-FM, which possesses better resistance than the 17% Cr alloy at both the temperatures used in this test; the somewhat higher nickel content plus the molybdenum in the 17% Cr-FM alloys probably accounts for this.

Grade	Weight Loss by Oxidation	
12% Cr	0.127% in 30 hr. at 1600° F.	7.18% in 8 hr. at 2050° F.
12% Cr-FM	0.128% in 30 hr. at 1600° F.	14.44% in 8 hr. at 2050° F.
17% Cr	0.408% in 24 hr. at 1700° F.	4.59% in 8 hr. at 2050° F.
17% Cr-FM	0.150% in 24 hr. at 1700° F.	3.62% in 8 hr. at 2050° F.
18-8	0.122% in 30 hr. at 1750° F.	0.76% in 8 hr. at 2050° F.
18-8 S-FM	0.170% in 30 hr. at 1750° F.	0.85% in 8 hr. at 2050° F.
18-8 Se-FM	0.183% in 30 hr. at 1750° F.	2.59% in 8 hr. at 2050° F.



Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys," Monograph No. 1, British Institute of Metals.

Emissions (by H.C. Vacher) Represent Values that Have Appeared in the Literature from 1936 to 1940 Inclusive.

Element, Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (Note a)	Axial Ratio c÷a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter Coordination No. 12 (Note f)	Reference (g)
Group IV A in Periodic Sequence										
22, Titanium	[2][8][10] 2	α = ○	1.601	6,6	2.953	4.729	2.915	2.953	2.93	—
	(slightly over 900°C.)	β = ◈	—	8	3.32	—	2.875	—	2.96	2
40, Zirconium	[2][8][18][10] 2	α = ○	1.589	6,6	3.223	5.123	3.166	3.223	3.19	—
	(data for 867°C.)	β = ◈	—	8	3.61	—	3.126	—	—	—
72, Hafnium	[2][8][18][32][10] 2	○	1.582	6,6	3.200	5.077	3.139	3.200	3.17	—
90, Thorium	[2][8][18][32][18][10] 2	□	—	12	5.077 or 5.091	—	3.590 or 3.600	—	—	—
Group IV B, Including Carbon and Silicon										
6, Carbon, diamond	[2] 4	◇	—	4	3.5606	—	1.5113	—	—	—
graphite		○ (b)	2.75	6	2.46	6.78	1.42	2.46	—	—
14, Silicon	[2][8] 4	◇	—	4	5.417 3±5	—	2.3457	—	—	1
32, Germanium	[2][8][18] 4	◇	—	4	5.647	—	2.445	—	2.788	—
50, Tin, gray	[2][8][18][18] 4	◇	—	4	6.46	—	—	—	3.164	—
white		△	0.5456	4,2	5.8194	3.1753	3.0161	3.1753	—	—
82, Lead	[2][8][18][32][18] 4	□	—	12	4.9389	—	3.4923	—	3.494	—
Group V A in Periodic Sequence										
23, Vanadium	[2][8][11] 2	◈	—	8	3.033 8	—	2.627 4	—	2.69	1
41, Columbium	[2][8][18][12] 1	◈	—	8	3.294±1	—	2.853	—	2.94	—
73, Tantalum	[2][8][18][32][11] 2	◈	—	8	3.295 9±3	—	2.854 4	—	2.94	1
91, Protoactinium	[2][8][18][32][18][11] 2	—	—	—	—	—	—	—	—	—
Group V B										
7, Nitrogen	[2] 5	α = cubic	—	—	5.66	—	1.06	—	—	—
		β = hex.	1.633	—	4.034±9	6.582±15	—	—	—	1
15, Phosphorus, metallic	[2][8] 5	□	a÷b÷c = 1 : 1.32 : 3.17		3.31	b=4.38 10.50	2.17	2.20	—	1
33, Arsenic	[2][8][18] 5	▱	α = 54°7.5′	3,3	4.13 5±6	—	2.507	3.139	—	1
51, Antimony	[2][8][18][18] 5	▱	α = 57°6.5′	3,3	4.497 6±2	—	2.879 5	3.378 4	3.228	1
83, Bismuth	[2][8][18][32][18] 5	▱	α = 57°14.2′	3,3	4.735 6±6	—	3.103 6	3.472 8	3.64	1
Group VI A in Periodic Sequence										
24, Chromium	[2][8][13] 1	α = ◈	—	8	2.878 6	—	2.492 9	—	2.57	—
		β = ○	1.626	6,6	2.717	4.418	2.709	2.717	2.71	—
42, Molybdenum	[2][8][18][13] 1	◈	—	8	3.140 3	—	2.719 6	—	2.80	—
74, Tungsten	[2][8][18][32][12] 2	α = ◈	—	8	3.158 3	—	2.735 2	—	2.82	—
		β = cubic (c) 8 atoms in unit cell			5.038	—	2.519	2.816	—	—
92, Uranium	[2][8][18][32][13][12] 2	□	4 atoms in unit cell		2.852	4.945	2.76	2.85	—	9
		a:b:c = 1:2.056:1.734,			b=5.865					
Group VI B										
8, Oxygen	[2] 6	α = □	4 atoms in unit cell		5.50	3.44	—	—	—	1
		a:b:c = 1:0.691:0.625,			b=3.82					
		β = ▱	α = 99.1°; 12 atoms in unit cell		6.19	—	—	—	—	1
		γ = cube	16 atoms in unit cell		6.83	—	—	—	—	1
16, Sulphur	[2][8] 6	α = □	128 atoms in unit cell		10.48	24.55	2.12	3.36	—	1
		a:b:c = 1 : 1.233 : 2.343;			b=12.92					
at 103°C.		(d) mono-	a:b:c = 1:1.011:1.006		10.90	10.96	—	—	—	7
		clinic	β = 83°16′;		b=11.02					
34, Selenium	[2][8][18] 6	○ (e)	1.140	2,4	4.337	4.945	2.316	3.457	—	—
		monoclinic (α)	a:b:c = 1:0.998:1.281		8.992	11.52	—	—	—	1
		32 atoms in unit cell, β = 91°34′;			b=8.973					
		monoclinic (β)	a:b:c = 1:6.311:2.261		12.74	9.25	—	—	—	1
		32 atoms in unit cell; β = 93°4′;			b=8.04					
52, Tellurium	[2][8][18][18] 6	○ (e)	1.33	2,4	4.445	5.912	2.858	3.46	—	—
84, Polonium	[2][8][18][32][18] 6	pseudo hexagonal	3 atoms in pseudo cell		4.25	7.06 or 14.12	—	—	—	6
		probably monoclinic	a:b:c = 1:0.578:1.900		7.42	14.10	3.4	4.0	—	6
		12 atoms in unit cell; β = 92°;			b=4.29					

Notes: (a) ◈ is body-centered cubic; □ is face-centered cubic; ○ is close packed hexagonal except as noted; ◇ is diamond; △ is tetragonal; ▱ is rhombohedral, and □ is orthorhombic.

(b) Graphite is hexagonal, not close packed, with four atoms per unit cell.

(c) Cubic structure; two positions distinguishable, X and Y. Each atom X has 12 Y at 2.816 Å; each atom Y has 2 Y at 2.519 and 4 X at 2.816 Å.

(d) Unit cell contains 48 S or 6 S_8.

(e) Hexagonal, not close packed; each atom has 2 neighbors at d_1 and 4 at d_2.

(f) Atomic diameters for new values have been computed by following Hume-Rothery's procedure whenever possible.

(g) See Page 580, Metal Progress, May 1941.

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SOME LATE DEVELOPMENTS IN OPENHEARTH STEEL PRACTICE

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THE NECESSITY for complete technical control of the openhearth process has been the incentive for recent metallurgical developments, as well as numerous improvements to the physical features of the furnace and its auxiliary equipment. These metallurgical developments and physical improvements have resulted from the economic need for larger and faster heats of consistent quality. The old idea that the highest quality could only be obtained from small, slow-working furnaces has been discarded since the development of the large modern furnaces capable of producing steel, of the highest quality, at rates of approximately 20 tons per hr. This extraordinary production rate is not due alone to increased hearth areas, but is the direct result of the coordination and consolidation of metallurgical and operating developments during the past ten years.

There is no feature of openhearth practice less amenable to control and more likely to disrupt a smooth operation than the charge. A well balanced charge is a necessity, but to maintain the desired balance between various materials is almost impossible. For example, the amount of ore charged must vary with the amount and type of scrap, the amount of iron and its silicon content. Also, the amount of limestone charged will vary with the amount of silica in the ore, the type of scrap and the amount and analysis of the iron. Although successive monthly averages of consumption of ore, limestone, scrap and iron may be fairly uniform, nevertheless, from day to day or even from charge to charge, the individual amounts or analyses of these materials may show wide variations. This is especially true of the scrap and hot metal, but, unfortunately, the variations in analyses and amounts of these materials consumed is usually beyond the control of the openhearth operator.

How seriously the variations in the silicon content of the hot metal will affect furnace time has been shown in data recently published by E. A. WHEATON in a paper entitled "Openhearth Operation on Low Silicon Basic Iron" before the Openhearth Conference of the A.I.M.E. in 1940. These data, as reproduced below, are the annual averages over a period of 10 years, and indicate that a reduction of 0.10% silicon in the hot metal corresponds with a reduction of approximately 30 min. in heat time.

YEAR	AVERAGE SILICON IN THE HOT METAL	HEAT TIME
1932	1.17%	10:21
1931	1.12	11:00
1933	1.12	10:09
1930	1.08	10:39
1934	0.97	10:27
1935	0.95	9:57
1938	0.85	9:27
1936	0.83	9:30
1937	0.79	9:12
1939	0.74	8:45

How far the trend toward lower silicon iron can be carried without adversely affecting blast furnace or openhearth operations will probably depend on the individual conditions prevailing in each shop.

As the silicon content of the iron is lowered, less limestone is needed in the charge in order to arrive at the desired lime-silica ratio in the finishing slags. The above data indicate that from the high of 1932 (1.17% silicon) to the low of 1939 (0.74%) the limestone consumption could be reduced by 72 lb. per net ton of ingots without altering the lime-silica ratio in the finishing slags (assuming a ratio of 3 to 1). As the amount of limestone in the charge decreases there is a noticeable shortening of heat times; however, the limestone consumption is largely dependent upon the amount of silicon in the iron so that these two factors are probably interrelated, insofar as they affect heat times.

The relation between limestone consumption and heat time may not be the same under all operating conditions, but the following data show the relation in one shop when using at least 55% hot metal in the charge:

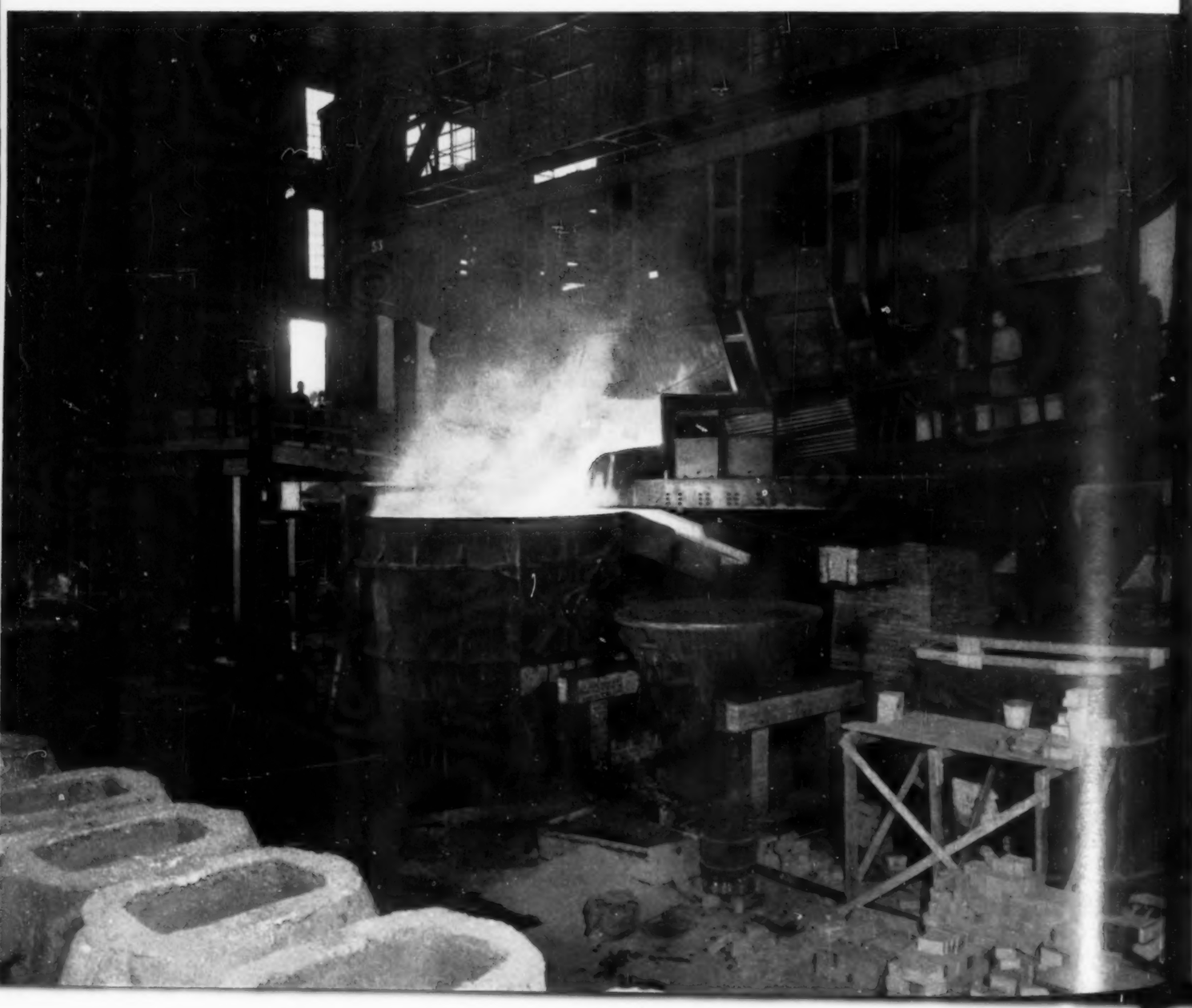
No. of Months Averaged	Lb. of Limestone per Net Ton	Heat Time
10	187	11:13
12	175	11:10
10	163	10:55
11	148	10:48

These data show that the shortening of heat time to be expected from a decrease in the limestone burden is about 10 min. for each 20 lb. decrease (per net ton of ingots) in the stone consumption.

The Sulphur Problem

Blast furnace operators have been impressed by the economies obtained in the openhearth when using iron low in silicon.

Tapping the First Heat From a 190-Ton Openhearth, 87 Days After Ground Was Broken. Normally oil-fired, a feature is three-pass regenerators (8400 cu.ft. volume) on each end of the furnace



phosphorus and sulphur and they are to be commended for the effort they have made toward producing the quality of iron desired for steel making. However, even under the most closely controlled burdens, iron analyses may show undesirably wide swings in silicon and sulphur from cast to cast. In turn, these variations are reflected to a greater or less degree in the openhearth operation.

In order to offset these variations in iron analyses either a modification of the steel furnace charge or a supplementary treatment of the iron is necessary. The general American practice is to modify the openhearth charge, although considerable work has been done to determine the economies resulting from supplementary treatments of the blast furnace product. It is likely that desulphurizing or desiliconizing treatments of blast furnace iron, as a routine practice, will be unnecessary by American steel plants as long as coals and ores of the present quality are available.

Such treatments are entirely feasible from a technical standpoint, but there are certain practical obstacles to be overcome before they can be considered successful. To be completely satisfactory, the siliceous slag or caustic slag resulting respectively from the desiliconizing or desulphurizing treatments must be removed by some skimming method before the treated iron is delivered to the mixer or refining furnaces. These slags will not only seriously erode the mixer linings, but if allowed to enter the openhearth furnace will nullify any benefits derived from treating the iron.

The unfavorable influence of sulphur on surface defects of rolled and forged products has become well recognized. Although the basic openhearth process can eliminate sulphur, nevertheless, a severe penalty is placed on the melter if he is required to produce low sulphur steels from materials high in that element. As the iron charged is one of the principal sources, any variation in its sulphur content will be directly reflected in the finished steel unless the openhearth operator consumes the additional fluxes and time required to remove the excess. The extent to which it should be eliminated, to avoid inferior surface quality, varies with the grade of steel and the manner in which it is to be hot worked or cold worked. Therefore, the efforts being made to control the sulphur content of the iron, either by natural means or supplementary treatments, should result in increased production from the openhearth furnaces or in an improvement in surface quality of the finished steel.

The striking effect of sulphur on surface quality is demonstrated by the data recently published by H. B. Emerick in *Blast Furnace and Steel Plant* for August 1940 ("Survey of Factors Affecting the Surface Quality of Semi-Finished Steel") in which the ladle sulphur content is related to the surface quality of seamless tube blooms of sound killed steel, and also for 1¾-in. billets of rimming steel. Emerick's data show that for seamless tube billets an increase from an average of 0.027% to an average of 0.035% sulphur will be accompanied by a four-fold increase in tube rejections for surface defects, in addition to a decrease of 22.5% in the chipping rate. Likewise, for the rimming grades an increase in sulphur is accompanied by increased scrap losses and reconditioning costs.

Whether or not the production of low sulphur steels is justified depends upon the magnitude of rejections in terms of lost production and increased costs. Before striving for low sulphur content of the finished product it is necessary to establish the balance between the cost of reconditioning and rejections under existing conditions and the economic penalty to be paid by the blast furnace and openhearth when required to produce low sulphur steels.

Slag-Metal Reactions

The general relationships existing between slag compositions and metal analyses have long been known in a qualitative fashion and slag compositions have been successfully manipulated to eliminate the necessary phosphorus and sulphur. Now, the old *art* of slag manipulation is rapidly being developed into the new *science* of slag control.

In the past six years several methods of control have been proposed and all seek the same final results — that is, to produce a slag in the furnace which will eliminate phosphorus and sulphur from the metal bath to the desired extent without waste of time or fluxes. In other words, the object of slag control is to allow faster working of heats while assuring that chemical specifications will be successfully met. It is futile to compare the specific control practices prevailing in different plants because the extent to which any method is applied will depend upon the silicon, phosphorus and sulphur content of the charge and the type of steel being produced.

The extent to which sulphur and phosphorus are eliminated depends upon the lime-silica ratio prevailing in the slag. The first objective of all methods of slag control is to estimate or measure this ratio promptly and accurately. On the basis of this estimate, corrective additions are made to the slag until the desired lime-silica ratio is obtained.

An outstanding contribution to our knowledge of slag-metal relationships was the work of K. L. FETTERS and JOHN CHIPMAN published in *Metals Technology* for February 1940 (A.I.M.E.) as "Slag-Metal Relationships in the Basic Openhearth Furnace" in which data from 650 metal and slag samples were studied by statistical analysis. Of the several correlations determined, the one in greatest conflict with previously accepted theories was that the degree of oxidation of the metal is more completely controlled by the carbon content of the bath than it is by the residual manganese or any of the components of the slag. Application of these findings should lead to a close control of deoxidation practices for rimming, semi-killed and also for killed steels, with the result the mold action, piping tendencies and grain size of these respective grades should be more uniform from heat to heat.

The meaning of the term "sufficient temperature" has a wide range of interpretation, largely because there is no method in common use which will accurately record openhearth bath temperatures. We can expect notable developments in this class of pyrometry, but thus far all proposed methods have failed to meet all the requirements of simplicity, accuracy, and ruggedness. The traditional method of determining bath temperatures by the experienced eye of the melter is simple, but, unfortunately, is not highly accurate. On the other hand, while the mechanical equipment — such as the immersion thermocouple, or the rayotube radiation pyrometer — appears to possess the required accuracy, it lacks the ruggedness necessary to withstand repeated or prolonged exposure to the erosive bath action and high temperature prevailing in the bath.

The requirements for a successful method of temperature measurement are not insurmountable, and it is likely that the wide-spread interest being shown in this field will eventually produce an instrument or method which will be enthusiastically adopted by openhearth operators. Aside from its influence on quality of the product, temperature control is important from a strictly operating viewpoint, since either excessively hot or cold heats will cause loss of production. Hot heats because of their tendency to attack the banks and bottom will require subsequent delays for patching the furnace. On the other hand, cold heats will develop large ladle skulls, generally accompanied by increased pit losses because of the failure to obtain a clean stopper in the teeming ladle.

Inclusions

During the past few years there has been an intensive study of the factors contributing to the prevalence of non-metallic inclusions in steel. As these inclusions are complex oxides and silicates their origin is frequently difficult to determine. Evidence has been produced showing that they may come from the charge or from the refractories, or may result from the entrapment of the products of deoxidation. The use of complex deoxidizing alloys which are designed to produce a fluid deoxidation product does not guarantee a product free from inclusions regardless of all other circumstances, and we must agree, therefore, that deoxidation practice or products are not the only source of "dirt in steel".

There has recently been considerable interest shown in the development of specially prepared hot-top insulators for ingots of killed steel. The growing popularity of these prepared insulators, in competition with such cheap materials as straw, oat hulls, sand, slag-wool and coke breeze, is an indication that the cheaper material may not always yield the soundest ingot with the greatest freedom from piping and segregation. On the other hand, if the physical laws of solidification and segregation of solid solutions are violated by using molds of improper design or sink heads of inadequate volume, then inferior ingots, with respect to piping and segregation, will be produced regardless of the material used to cover the top of the sink head.

In conclusion it may be said that the last decade has witnessed — if not any major and startling revolutions in the melt shop — a gradual improvement in our knowledge of the essentials of steel making, and a steady gain in equipment, ability and desire to apply this knowledge. The net result is that today we are undoubtedly able to make better steel at a higher rate than ever before in metallurgical history.

METALLURGICAL FACTORS IN THE SELECTION OF STEELS

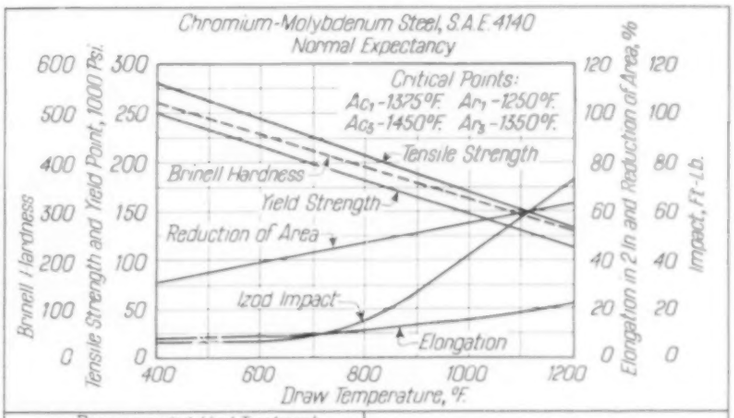
By **Gordon T. Williams**
Metallurgist
Deere & Co., Moline, Ill.

IN THREE preceding papers (adopted from a series of lectures before the Tri-City Chapter, A.S.M., early in 1941) some general remarks were made about the physical testing of metals, and how the results of those physical tests aided the designer and the metallurgist to select a suitable steel for a given job. Beyond these *physical* tests — such as tensile, notch bar, fatigue, hardness — there are a few *metallurgical* properties that require attention.

The metallurgical properties we need to worry about that determine the useful properties of steel are not very many. We are not going to talk now about details of heat treatment, critical points, critical cooling rates, and similar matters, but those things we must bear in mind in selecting steel.

Chemical analysis is least important. Don't take that quite as baldly as it sounds; the *type* or family of steel is very important — whether we pick chromium-nickel or plain carbon, say. But when we have steel that appears right, the question of percentages of this or that element is not nearly so important as some have been led to believe. The permissible range for a common chromium-nickel steel is 0.45 to 0.75% chromium, 1.0 to 1.5% nickel; variations within that range have *some* effect, but the effect is a minor one and may often be overshadowed by other things.

General data on representative properties of dozens of much used steels are available from any steel company. A typical chart is shown in Fig. 1, and happens to represent S.A.E. 4140, 1% Cr, 0.20% Mo, 0.40% C. It contains the recommended heat treatment, forging temperature, quench, normalizing, annealing, or quenching temperature, size of piece treated to give the tabulated results, the critical points, chemical specifications (and often the analysis of particular sample used). Curves show the Brinell hardness, tensile



Recommended Heat Treatment			Chemical Specification	
Operation	Temp., °F.	Cool		
Forge	2000-2200	Slow	C % 0.35 to 0.45	Ni %
Normalize	1600-1700	Air	Mn % 0.60 to 0.90	Cr % 0.80 to 1.10
Anneal	1500-1550	Furnace	P % 0.04 Max.	Al %
Quench	1525-1575	Oil	S % 0.05 Max.	V %
Test Piece Treated in 1-Inch Round			Si %	Mo % 0.15 to 0.25

Fig. 1 — Typical Property Chart for Alloy Steel, Quenched From Normal Temperature and Drawn at Various Ranges. Courtesy Climax Molybdenum Co.

strength, yield point, elongation in 2 in., reduction of area, and Izod impact, all as they vary with the drawing temperature. The curves show, for instance, that after quenching in oil from 1525 to 1575° F. and drawing at 800° F., the reduction of area is about 47%, elongation is about 12%, and Izod impact is about 15 ft-lb. For any other draw temperature, we can find the expected properties of the center ½-in. of a 1-in. round. If we require a certain tensile strength or yield point, we can find the other corresponding properties and heat treatment required.

Usually the yield strength, the proportional limit or the hardness is used to select material to have necessary resistance to deformation. Hardness of course is a function of the tensile strength; the other properties will vary according to the chart and must be a secondary consideration. If they don't come right in S.A.E. 4140, another type analysis may be better in a specific respect.

After the *family* or type of steel has been chosen, do not worry too much about the incidental elements. For example, sulphur and phosphorus are not important elements when controlled within specified chemical limits. Beyond that, they contribute to strength and brittleness. They promote machinability and therefore sometimes we ask for them, but only with the realization that they will undoubtedly harm the toughness and ductility of steel.

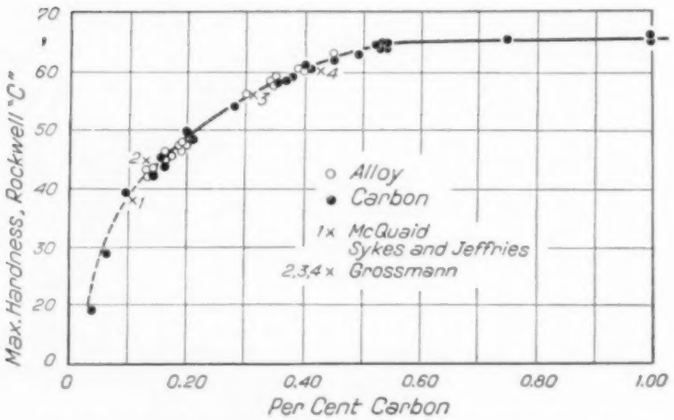


Fig. 2 — Maximum Hardness Obtainable in Steel Is a Function of Its Carbon Content Rather Than of a Moderate Amount of Alloying Elements. (Burns, Moore & Archer)

Carbon is the most important single element in steel; Fig. 2 shows why. On this are plotted the maximum hardness values obtainable with plain carbon and several alloy steels. When quenched in such a manner to develop the maximum hardness, all hardnesses fall on the same curve, plotted according to carbon content. The fundamental point is that maximum available hardness depends on carbon content. Note that I say *available* hardness — we may have to improve the hardenability of a steel so that we can attain that maximum hardness, but after we have improved hardenability we can only reach the capability of a good carbon steel.

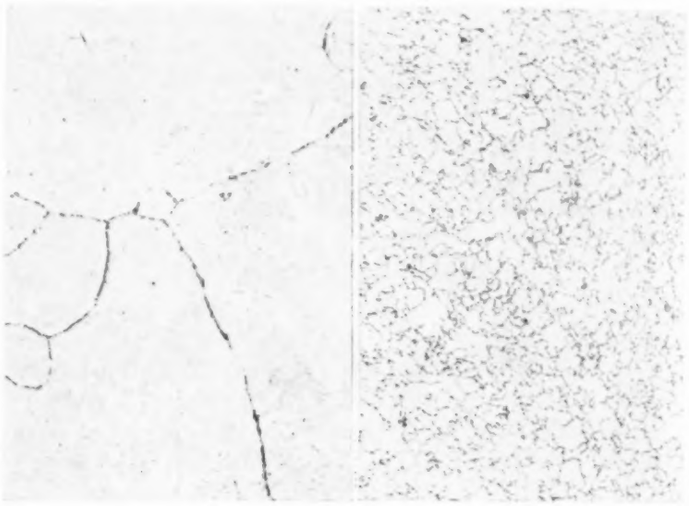


Fig. 3 — Wide Variations in Grain Size in Steel, Etched so as to Darken Carbides at Grain Boundaries and Examined at 100 Diameters. Left is S.A.E. 1015 plain carbon steel soaked at 1700° F.; right is a very fine-grained nickel-molybdenum steel of the same carbon content, S.A.E. 4615. (Grossmann's "Heat Treatment")

Manganese is probably the next most important element to carbon. It is present in all steels from about 0.30% to as much as 0.90%, even in the plain carbon steels. Some S.A.E. *alloy* steels run as high as 1.90% in manganese. Manganese may be said to be our cheapest alloying element.

Alloying elements — the basis for selecting steel for heat treating — will be taken up at a later time, when I will show that the alloy type is relatively unimportant, for all common types of alloy steel can develop approximately the same physical properties. There must be other bases for selecting the steel to be used for a given part than its alloy content.

In all carbon and alloy steel made from scrap there are high percentages of residual elements. Copper is one; a typical analysis of openhearth steel made from a high scrap charge

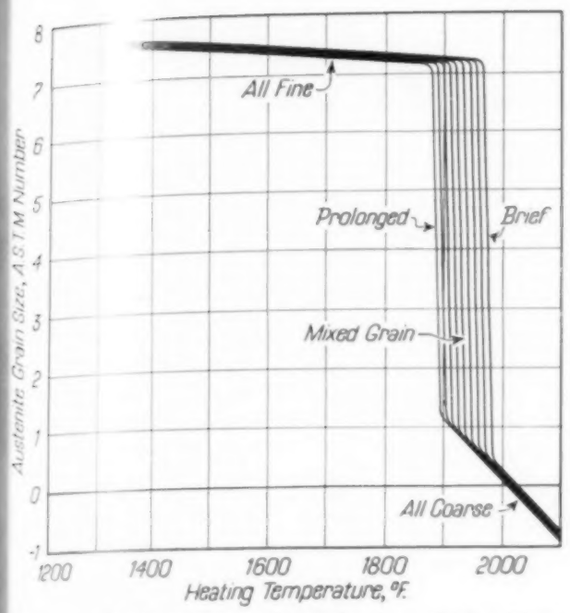


Fig. 4 — Aluminum-Treated Steels Are of the Type That Coarsen Abruptly at a High Temperature. (Bain)

will show 0.15 to 0.20% copper. It is unfortunate that copper once in steel does not get out; manganese we want so badly and lose so easily to the slag in steel making. Copper we don't particularly want and can't get rid of!

Gases in steel are important but are not under control. (Sulphur and phosphorus are important but are under control.) Control of inclusions, and gases like oxygen, nitrogen, hydrogen, is even yet rather uncertain. Only recently has the technique of testing improved to a point where we are able to show that damage *is* done by these gases. Control will follow.

Grain Size Control

The most important factor in the heat treatment of steel is the grain size, by which we mean the size of the microscopic grains which is established at the maximum temperature to which the piece of steel is heated. Grain size, in this sense, is also related to the temperature at which grain growth starts.

Very coarse and very fine grains are shown at 100 diameters in Fig. 3. While these are extremes, it should be remembered that grain size is a very important metallurgical factor in the selection of quality steel.

Grain size control is nobody's secret. Controlled steels are readily available and most companies are using them today. Some steels which are fine-grained (A.S.T.M. No. 7) after heating to 1400° F. will gradually coarsen with time at higher temperatures, reaching grain size zero at about 2000° F. On the other hand, aluminum treated steels, if properly made, maintain their original fine grain to well above carburizing temperatures and then coarsen rapidly. Figure 4, from E. C. Bain's valuable book, "Functions of The Alloying Elements in Steel", shows that up to a temperature of better than 1800° F. this particular steel stayed fine-grained; it coarsened very slightly — not one A.S.T.M. number. Then, depending on time at temperature, it coarsened and at 1900° F., all grains were coarse. The steel has some retarding influence which regulates its grain size to a certain temperature; once that temperature is reached, the grains grow rapidly.

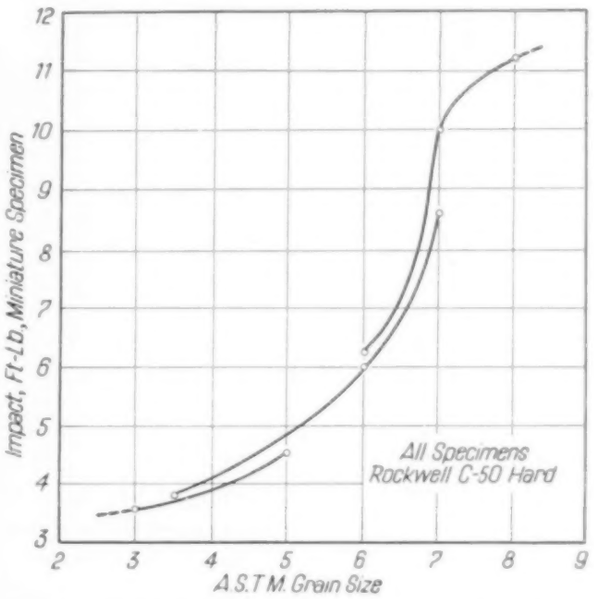


Fig. 5 — Ratio of Prior Austenite Grain Size to Energy Absorbed in Breaking Miniature Specimens of Eutectoid Steel, Hardened to Rockwell C-50. (Bain)

Why are we interested in grain size? We have good reasons; perhaps three are most important to us:

1. Fine-grained steels show better toughness at high hardness. Figure 5 shows the results of

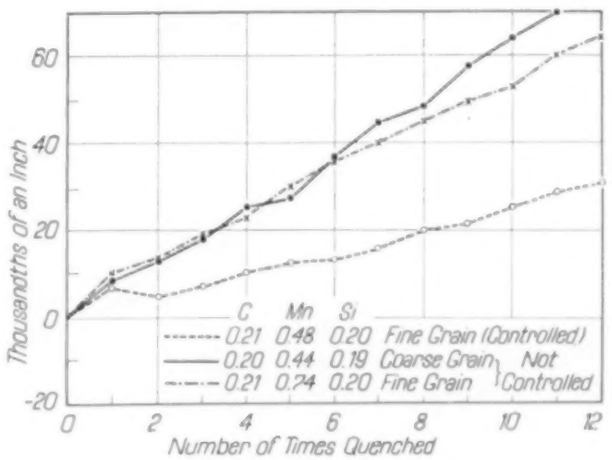

Thousandths of an Inch
C Mn Si
0.21 0.48 0.20 Fine Grain (Controlled)
0.20 0.44 0.19 Coarse Grain Not Controlled
0.21 0.24 0.20 Fine Grain
Number of Times Quenched

Fig. 6 — Controlled Grain Size Steel Has Less Warpage Than Steels of Same Grade Without Grain Size Control. (From "Carnegie Controlled Carbon Steels")

impact tests made on a given steel heat treated so its grain sizes ran from No. 2 to 8. Impact values in foot-pounds were recorded using unnotched bars, because values with notched bars were so low. The coarsened steel (grain size No. 3) tested 3.5 ft-lb.; grain size No. 5 was 5 ft-lb.; at grain size No. 7 the energy absorbed was 9 ft-lb. This is typical and no special case.

2. Grain size controlled steels will show less warpage, as Fig. 6 (page 723) points out. It records the "number of times quenched" versus "distortion" or warpage measured on the outside diameter of a C test specimen used in U. S. Navy specifications. Three steels of a definite grade (0.40 carbon) and closely similar analysis in carbon and silicon were tested. One specimen was fine-grained, of controlled grain size. The other two specimens were non-controlled steels, but one was fine-grained within the temperature of quenching and the other was coarse-grained. Notice the distortion across the open end of the "C" was less than one-half for the controlled as compared to the non-controlled grain size steel with any number of quenchings from two to 12.

3. On the other hand, coarse-grained steels harden better. BAIN gives us Fig. 7 showing how the hardness, edge to center, of a 1-in. round varies with the grain size; steel, quenching temperature and other factors remaining constant. Various grain sizes were established by heating to various temperatures as noted before bringing quickly to quenching temperature. Note that the bar with grain size No. 2 has a center hardness of C-50; with grain size of 5, we got only C-38 at the center.

Grain size control is secured in the steel mill by the deliberate production of certain minute inclusions, which evidently scatter as desired. The purchaser must specify grain size, but controlled grain growth steels are readily available. A high percentage of carbon steels used for heat treating is grain size controlled and sold to grain size limits. Almost all the alloy steel is grain size controlled.

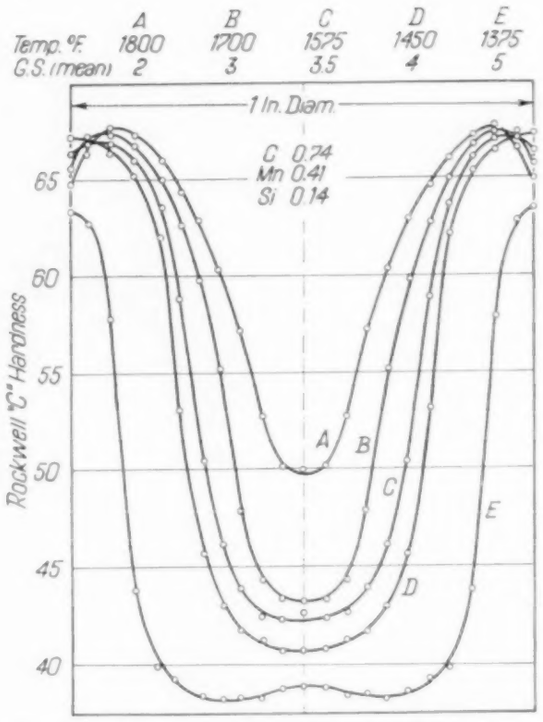


Fig. 7 — Influence of Austenitic Grain Size Upon the Hardenability of a 1-In. Round of 0.75% Plain Carbon Steel, Water Quenched From Identical Temperature. Grain sizes and temperatures required to establish these grain sizes are noted at the top of the figure. (Courtesy of E. C. Bain)

Inclusions represent dirt in steel — but this dirt seems to be highly necessary for grain size control. Inclusions may be deliberately produced by regulating the percentage of sulphur and phosphorus in order to improve machinability; they seem to act as points of weakness, and act by causing brittleness of the chip, so it breaks freely. They also give a chip that will not pile up on the cutting tool. Inclusions that are not required for machinability or grain size control are embrittling and should be avoided if possible. The aircraft industry is fussy about the "dirt content" or "inclusion rating" of steels it uses. That is reasonable, since the factor of safety in terms of pilot's and passengers' safety is much higher, yet the design must be refined to a point where no excess metal can be carried.

Inclusions are like any other form of notch — they are internal notches and are far more damaging on hard steels than on soft steels. This is obvious if you turn to the figures and remarks about notches in the previous articles on impact and fatigue. Inclusions are stress raisers in themselves because they are discontinuities in the steel; such notches may easily occur at some point where stress is already high. An example would be on the pitch line of gear teeth — the stress is already high and then, with stress raisers present, stress concentration is raised still higher and failure results.

Hardenability

"Hardenability" is the modern metallurgical battle cry! It is the latest evolution of chemical analysis and grain size control. It means specifying what is required in the way of response to heat treatment. It has been under discussion for many years, and very intensively for the past three or four years. It looks as if it is set-

tling down to a useful test of a property which can be specified.

The modern concept is quite fundamental. Hardenability is some form of expression which depends on the critical cooling rate of the steel, or the speed with which it must be cooled in order to harden. We may have to specify steel on the basis of hardenability when we do not need high quality, if we want to be sure that the section will harden all the way through. Steels of different hardenability may require an air cool, water quench, or oil quench, and steels of various thicknesses will require cooling at the center at the correct rate to harden.

There are two fundamental ways of checking hardenability:

1. Quench a bar of given size and take hardness traverse, such as was done for Fig. 7; a comparison of this hardness traverse with others will show the differences in hardenability.

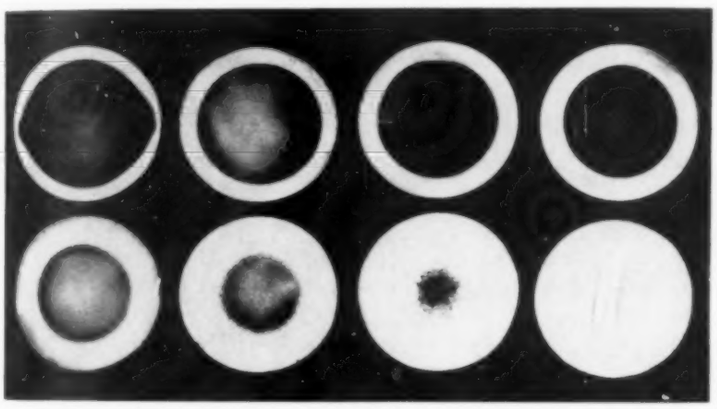


Fig. 8 — A Group of 1-In. Bars of Carbon Steel, Quenched, Cut and Lightly Etched to Show Soft Center. One hardened completely. (Bain)

2. We can check bars of various diameters, or we can check bars of a fixed diameter. For that purpose, 1-in. rounds are very useful if the material is such that it does not harden all the way through in the standard quench. Figure 8 shows the cross-sections of eight different bars of eight different hardenabilities. These are 1-in. rounds, cut after hardening, etched to show the hardened rim and the soft center. They vary from a very thin skin, typical of carbon toolsteels, up to steel hardened all the way through.

Figure 9 shows the hardness traverses of these steels. The one hardened all the way through is No. 8; it shows about Rockwell C-63 at the center of the 1-in. round. Number 1 with the thin skin is about C-67 at the surface, but within $\frac{1}{32}$ in. is down below C-50, and the center is down around 40.

Such a hardness test is very useful for steels which do not harden through in 1-in. rounds; if you test larger sized bars, there is no limit to the application, other than the problem of cutting the hardened bar, which is hard to do without tempering the hardened surface and without taking too much time.

Another method for determining hardenability consists of heating the 1-in. bar to a hardening temperature and then setting it over a jet of water which hits only the bottom face. Consequently, on the *side* of the specimen we have various cooling rates, and later can measure hardnesses representing cooling rates all the way from that of a water spray down nearly to an air cool. This is a wide range test, yet its results can be correlated with tests on fully quenched bars, and with work on actual parts. The reader may refer to two recent articles by WALTER JOMINY, the originator of the idea, in METAL PROGRESS, November 1940, p. 685, and April 1941, p. 447.

Such a correlation is contained in Fig. 11. This plots the distance away from the water-cooled end against the Rockwell C hardness observed. In testing two bars of S.A.E. 4150 (No. 5 and No. 6) we find that even out 2½ in. away, where the cooling rate is almost as slow as in air, the hardness is only down to C-42. The two heats of S.A.E. 3150 show some differences and yet the hardness at 1½ in. from

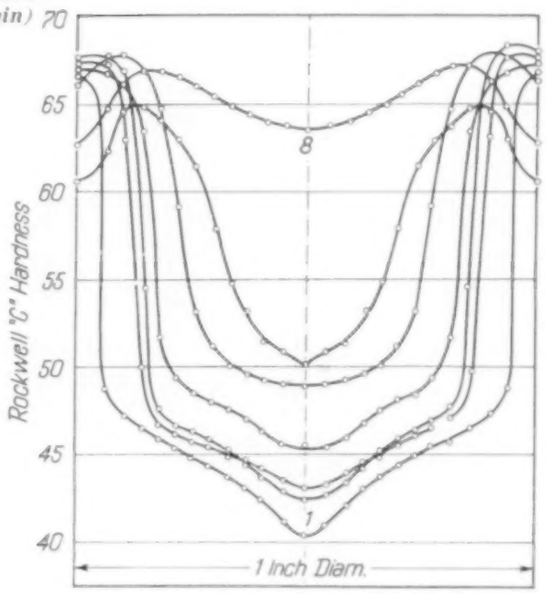


Fig. 9 — Hardness Traverses for the Eight Steels Shown in Fig. 8

the end is C-30, and 2½ in. is only down to C-20 to 30. In the two heats of plain 1050 carbon steel, notice how rapidly the hardness falls off within ¼ in. of the surface. (By the way, all of these are fine-grained steels.)

The correlation with cooling rates at the center of equivalent bars was established by JOMINY at General Motors Research Laboratories, and he gives the vertical dotted lines. The cooling rate at ¾ in. from the water-cooled end is the same cooling rate as found at the center of a 2-in. round, quenched in oil. Two-inch bars of these various steels were therefore heated and quenched in oil, cross-sectioned and the center hardness taken. These black cross marks represent the center hardness so observed; note how well they agree with the data arrived at from the value given us by the end-quench test. A point approximately 1¼ in. from the water-cooled end cools at the same rate as would have obtained at the center of a 3-in. round quenched in oil. The checks shown by black arrow heads are not quite as good here, but nevertheless they indicate a very nice correlation.

I might point out another useful thing: We may make a gear or a shaft from a particular steel and find that at some point in that shaft we had a Rockwell hardness of C-50; we then run a Jominy hardenability test and find C-50 at 1/16 in. from the water-cooled end. Now we may be confident that any other steels, which on a Jominy hardenability test will show C-50 at 1 9/16 in. from quenched end, will quench out much like the original one did, when they are made into the same kind of part.

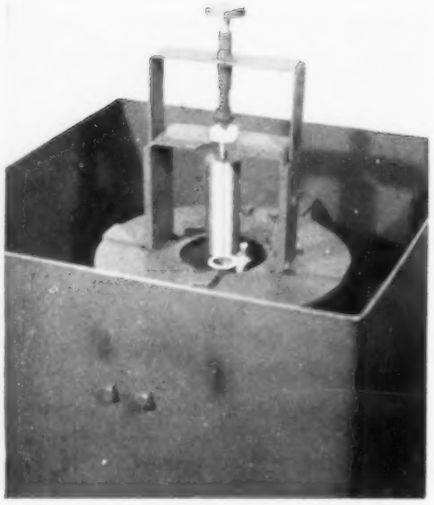


Fig. 10 — Apparatus for End-Quench Test

The table below, collected from various sources including the writer's own experience, shows the sizes of bars that are fully hardenable — that is, will develop a hardness of at least Rockwell C-50 at the center when quenched as indicated.

Size of Bars Fully Hardenable
(Rockwell C-50 Min. at Center)

S.A.E.	Water Quench	Oil Quench	S.A.E.	Water Quench	Oil Quench
1050	¾-1"	..	3130	1⅛	⅞
1330	1¼	1⅛	3140	1⅝	1
1340	1¼	1⅛	X3140	2½	1¾
2330	1	½	4150	3½	2½
2340	1⅜	⅞	4340	6+	4
5130	1	½	6150	1⅜	⅞
5145	1½	⅞	3240	4	3

These are pretty interesting figures, particularly when you correlate them with steel prices. You will see that S.A.E. 2340 (more expensive than 4150) is much less hardenable. (We will also see in a later article that the physical properties obtained on 4150 are just as good.) The 1300 steels are practically as good as 3½% nickel or chromium steels in the matter of depth of hardening; they are almost as good as nickel-chromium steels. Such a summary as this reminds us that we must select steels with economy in mind. We want the maximum development of available properties, but higher cost does not mean that the steel is better.

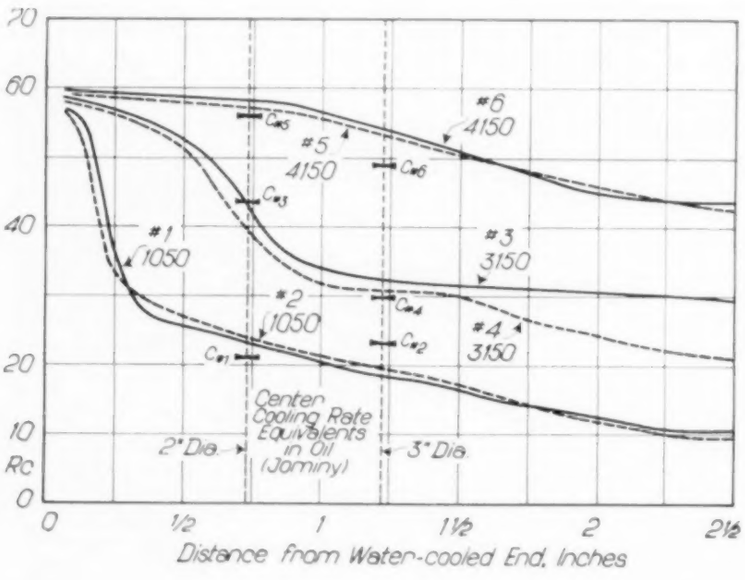


Fig. 11 — Hardness Along the Side of Bars, End-Quenched in the Jominy Test

"I judge the telephone company by the people who work for it"

A little while ago a Vermont newspaper editor, John Hooper, commented on the telephone company and its people. His words express so well the ideals toward which we are striving that we quote them here.

"I DON'T know how big the telephone company is, but it is big enough to exceed my mental grasp of business.

"But I don't find myself thinking of it as a business, even in my day-to-day contacts. Rather, my attention is on the voice that says, 'Number, please.' I find myself wondering if that voice is feeling as well as it always seems to, or if it feels just as hot and weary as I do, and would say so if it wasn't the kind of voice it is.

"The first time the business angle really struck home was when I read that my friend Carl had completed thirty years with the company.

"Now it happens that I know something of the details of those thirty years with the company, and I believe they are a credit both to Carl and to the big business for which he works.

"In 1907 Carl was a high school boy confronted with the need for earning money in his spare time. He happened to get a job as Saturday night operator in the telephone exchange. He worked at this job for three years and then entered the university.

"While in college he did some substituting at the exchange in his home town in vacations. After graduation, he was hired full time by the telephone company, not in an 'executive' position which some folks think goes with a college diploma, but as a lineman.

"Within a year he was made wire chief of the district, a job which he held for the next ten years. He was then transferred to a larger city as manager of the office. Then he was promoted to sales manager of the division.

"A year later he was sent to another State, as district manager. In less than a year after this appointment, he was made manager for the entire State.

"I don't know much about the telephone company as a business; I can only judge it by the people who work for it. Just where the dividing line is between a business and the people who work for it, I don't know. I don't think there is any line."

Bell Telephone System

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PERSONALS

James B. Hess ⊜, formerly junior metallurgist, J. H. Williams & Co., Buffalo, is now a metallurgist for the Dow Chemical Co., Midland, Mich.

Joseph A. Sarandria ⊜ has joined Chisholm Boyd & White Co. as a ceramic engineer.

C. G. Chambers ⊜, formerly chief metallurgist, Reo Motors, Inc., Lansing, Mich., is now chief metallurgist, Wayne Division, Bendix Aviation Corp., Wayne, Mich.

G. B. Anderson ⊜, formerly with the Breeze Corp., Newark, N. J., is at present project engineer in the research department of Librascope, Inc., Glendale, Calif.

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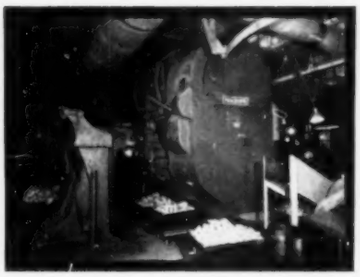
ROTOBLASTING

(IN FACT — CAN'T AFFORD NOT USING IT!)



★ ★ FOR SPEED ★ ★

"ROTOBLASTING" means faster cleaning—faster removal of sand and scale—and faster delivery of finished product. Excuses and apologies are worthless today—only performance and delivery count. If your shipments are delayed because of blast cleaning slowness, your customers will buy from plants they can depend upon. They will buy from plants that ROTOBLAST their work to assure leadership in blast cleaning. That's why the army of Pangborn airless Barrels, Tables and Special Machines is growing so rapidly. ROTOBLASTING is SPEEDY!

★ ★ FOR ECONOMY ★ ★

"ROTOBLASTING" is economical! When cleaning time is cut 2 or 3 hours per day—when one man finishes in half a shift what five men formerly did in their combined full time—when power and labor and wear are all reduced to a fraction of their previous cost—that's economy! ROTOBLAST economy.
More work is better cleaned—in quicker time—at less cost per ton—than ever before. Less fuss and bother. More production. Less dollar cost. No wonder installations are gaining so rapidly. ROTOBLASTING is ECONOMICAL!

Send for descriptive literature today

PANGBORN

WORLD'S LARGEST MANUFACTURER OF DUST COLLECTING AND BLAST CLEANING EQUIPMENT
PANGBORN CORPORATION . . . HAGERSTOWN, MARYLAND

H. W. Graham ⊜, director of research for Jones & Laughlin Steel Corp., Pittsburgh, has been named chairman of the Committee on Iron and Steel of the National Research Council's South American Committee.

H. H. Bleakney ⊜ is now chief metallurgist with the newly formed Federal Foundries and Steel Co. at London, Ont.

Transferred: **Arthur J. Sikora** ⊜, from assistant metallurgist and foundry technician for Wright Aeronautical Corp., to director of laboratories, Cincinnati Division.

L. P. Tarasov ⊜ is now metallurgist in the mechanical section of the Norton Co. research laboratories.

L. K. Vry ⊜ of Caterpillar Tractor Co. is now a dollar-a-year man with the OPM in Washington as assistant to the chairman, Tool and Equipment Priority Group in the Priority Division.

J. Tucker MacKenzie ⊜ is now with the metallurgical laboratory at the Wood Works of Carnegie-Illinois Steel Corporation in McKeesport, Pa.

Edgar K. Mull ⊜ has returned after nine years in England and is now chief metallurgist with Bendix Radio Corporation, Baltimore, Md.

Transferred by Magnetic Analysis Corp.: **J. D. Wilfong, Jr.** ⊜, from sales and service engineer of the Pittsburgh district to development engineer at the laboratory in Long Island City, N. Y.

Alex R. Schoonover ⊜, formerly with Universal-Cyclops Steel Corp., Bridgeville, Pa., is now an ordnance material inspector for the Cincinnati Ordnance District.

Cecil J. Bier ⊜ is now employed as metallurgist for the Moraine Products Division of General Motors Corp., Dayton, Ohio.

WHY WAIT IN LINE FOR ORDNANCE FURNACES—

FLINN AND DREFFEIN CAN SHOW YOU A QUICKER WAY

To give *immediate* attention to your furnace problems, we have expanded our drafting, engineering and fabrication facilities. Backed by 34 years' experience in furnace building—including the frenzied industrial rush of the World War—our staff of furnace engineers is especially trained in ordnance work.

Whether it's the production of shells, bombs, tanks, aeroplane parts, guns or armor plate—F & D can engineer an efficient, economical solution.

Many of our standard furnaces can be changed over to handle all types of ordnance work in a very short time. These furnaces have been improved and developed through 34 years of manufacturing every type of heat treating furnace.

In this time we have designed and built furnaces for: forging . . . hardening . . . annealing . . . billet heating . . . drawing . . . carburizing . . . bright annealing . . . controlled atmospheres . . . scale-free hardening . . . bright hardening . . . scale-free annealing . . . normalizing . . . special atmosphere . . . sheet and pair . . . plate heating . . . quenching and heat treating machines . . . continuous conveyor furnaces of all kinds.

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FLINN & DREFFEIN
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308 WEST WASHINGTON ST., CHICAGO, ILLINOIS

PERSONALS

Thomas L. Fritzlen, formerly metallurgist, Aluminum Co. of America, is now with Reynolds Metals Co. in Louisville, Ky.

Herbert V. Thaden has been appointed manager, Commercial Department, Duramold Aircraft Corp., New York City.

E. E. Legge has resigned as assistant director of research, American Steel & Wire Co., Cleveland, to become general manager of Hart Mfg. Co., Hartford, Conn., manufacturers of electrical switches.

Russell Lowrey has resigned as metallurgist with the Hydril Co. to become metallurgist and plant manager, California Steel Treating Corp., Los Angeles.

Vance Ferguson has been transferred from American Steel Foundries Research Laboratory to assistant chief chemist of the Granite City plant.

Eugene Tsao, D.Sc. in metallurgical engineering, University of Michigan, is now metallurgical engineer of the Universal Trading Corp., New York City.

Transferred to the Christy Park Works of National Tube Co. and appointed assistant chief metallurgist: **William R. Davis**, formerly in the Pittsburgh office.

Promoted by Pittsburgh Steel Co.: **Charles L. Labeka**, from openhearth metallurgist to plant metallurgist in the Monessen Works.

Frank O. Fischer, for more than 12 years with Magnetic Analysis Corp., has recently been promoted to chief sales and service engineer.

Donald Lapenta, formerly with Unitcast Co., Toledo, Ohio, is now metallurgist with Commerce Pattern Foundry and Machine Co., Detroit.

William B. Brooks has resigned as metallurgist, Stainless Steel Division, Carnegie-Illinois Steel Corp. to accept a position as metallurgist for Cramp Shipbuilding Co., Philadelphia.

Henry Orth is now working as assistant metallurgist at the Stewart-Warner Corp., Chicago.

J. L. Miller has left Illinois Institute of Technology to serve as metallurgist for the Firestone Tire & Rubber Co., Akron, Ohio.

J. W. Barnet, formerly with the Continental Can Co. Research Department, is now associated with the Tin Research Project at Battelle Memorial Institute, Columbus, Ohio.

Transferred by Brown Instrument Co.: **K. L. Wilson**, from the Indianapolis office to the Cleveland office as industrial manager.

ARE YOU OVERLOOKING THIS POWERFUL PRODUCTION TOOL?

The problems of increased production are so many and varied that simple solutions are often hidden and difficult to perceive.

Obviously, it is necessary to squeeze every ounce of production efficiency from existing tools and machines. This can best be accomplished when cutting fluids are seriously recognized as a factor of prime importance. Perhaps you have overlooked the useful developments in the field of cutting fluids that have accompanied improved machine and tool designs. The importance of such developments is evidenced by the interest in intensive research under way in the laboratories of leading universities and machine tool manufacturers.

When a plant door is unwittingly closed to the results of scientific progress in the field of cutting fluids and cutting fluid applications, its production executives are neglecting to use a valuable and immediately available working tool.

As a production executive interested in getting more out of existing tools and machines, by eliminating such superfluities as tradition, reciprocity, etc., will you consider the following suggestions? They may solve your problems.

WHAT YOU CAN DO ABOUT IT!

1. Encourage your purchasing agent to consider bona fide new cutting oil developments. Ask him to open the door wide to the qualified vendors possessing the all important credential of well founded information on the lubrication problems of today.

2. Remind your factory manager, superintendent or test engineer that the policy of trying out well recommended cutting oil products can be of vital importance and may quickly open up bottlenecks in the road to increased production.

3. Suggest to your metallurgist that machinability troubles can frequently be cured by getting the right cutting oil to fit the job, preferably selecting one with a sufficient factor of safety to provide for occasional metallurgical irregularities.

4. Inform your tool engineer that when deliveries of small tools are slow or difficult to obtain, it may be that the opening of the door and the help of a qualified cutting oil engineer may prolong the life of the tools on hand, thereby reducing appreciably this particular bottleneck in a quick and simple way.

WHAT WE CAN DO ABOUT IT!

1. We can through an informed and alert personnel immediately present to your organization timely information covering the most efficient cutting oil applications for ALL metal cutting operations. At the present time the problems involved in the manufacture of gun barrels and mechanisms, military tanks, ammunition, airplane engines and other similar items are, because of the emergency, particularly important.

2. We can present to you complete cutting oil research facilities, together with broad practical experience gained from working hand in hand with the manufacturers of small tools, builders of machine tools and makers of alloy steels.

3. We can give you the benefit of years of experience in supplying cutting oil products and cutting oil engineering service to the largest consumers in the most highly competitive industries. We are today providing government manufacturing plants (armories and arsenals), airplane engine builders, and the earlier manufacturers of munitions with a quality of cutting oil products and a specialized cutting oil application service that saves tools and speeds up production.

YOU OPEN THE DOOR—WE WILL SERVE YOU WELL

D. A. STUART OIL CO.
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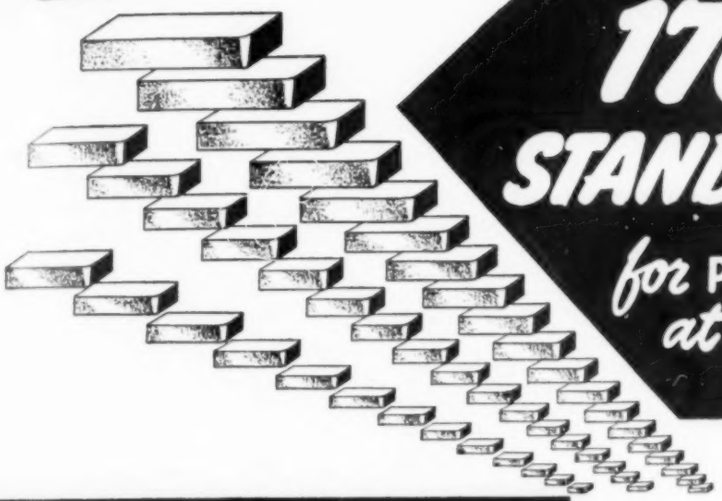
2727-2753 SO. TROY STREET • CHICAGO, ILL.
Warehouses in Principal Metal Working Centers

MORE FIRTHITE TOOL TIPS!

(SINTERED CARBIDE)

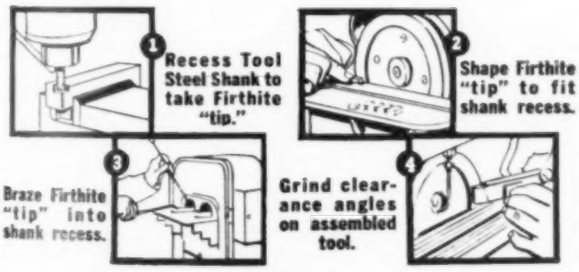


176 NEW STANDARD SIZES

for PROMPT DELIVERY at LOWER PRICES

MAKE YOUR OWN FIRTHITE CARBIDE TOOLS!

Don't slow up production for lack of enough Cutting Tools. Join the increasing group of manufacturers who make their own FIRTHITE Tools from Standard FIRTHITE Tips. Only FOUR basic steps are required to make these superior tools *in your own shop*. Information on request.



We have added 176 NEW Standard Sizes to the FIRTHITE line of Carbide TIPS for making your own Cutting Tools. Increased production facilities assure *prompt* delivery of all *standard* tips and special low prices. FIRTHITE Standard Tips now embrace almost the whole field of single point tool requirements and will fit a wide variety of special tools. Sizes range from 1/16"x5/32"x1/4" up to and including 1/2"x3/4"x1 1/4" in styles and grades to meet your needs.

Send for new STANDARD TOOL TIP Stock and Price List now!

FIRTH-STERLING STEEL COMPANY

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McKEESPORT, PA.
BRANCH WAREHOUSES:
NEW YORK CHICAGO
HARTFORD PHILADELPHIA
LOS ANGELES DAYTON
CLEVELAND DETROIT

PERSONALS

Paul L. Butler has moved to Columbus, Ohio, to take a position as research engineer at Battelle Memorial Institute.

R. F. Marande has accepted a position in the metallurgical research laboratory of the Dow Chemical Co. in Midland, Mich.

W. E. Griffiths has resigned as representative of the Stainless Steel Division of the Carnegie-Illinois Steel Corp. to accept a position as manager of the Development Engineering Division of Allegheny Ludlum Steel Corp., Pittsburgh.

Frank W. Littleford is now employed as chief metallurgist by the Oliver Farm Equipment Co., Charles City, Iowa.

SPEED CASE STEEL

A LOW CARBON OPEN HEARTH PRODUCT

Assures You . . .

1. PHYSICAL PROPERTIES
Tensile 70—85000 PSI *Yield* 60—75000 PSI *El. in* 2"—17-22% *R A* 52-60% for 1" Round cold drawn bar. Excellent shock and fatigue values.

2. UNUSUAL DUCTILITY
180° Bend (Cold Drawn - 1" Rd)

3. SMALLER INVENTORY
Due to Versatility of Speed Case

4. INCREASED PRODUCTION
40% to 80% Over SAE X1020-X1314, etc.

5. MACHINABILITY
Machines as fast as SAE X1112

6. CARBURIZING
Carburizes like SAE X1020

JOBBERS NOTE!
Reduce Your Inventory
SPEED CASE
the ALL PURPOSE Steel
will allow you to reduce the number of different steels you are now carrying in your stock.
ASK US FOR DETAILS

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MONARCH STEEL COMPANY
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Licensee for Eastern States
THE FITZSIMONS COMPANY
YOUNGSTOWN, OHIO

MANUFACTURERS OF COLD FINISHED CARBON AND ALLOY STEEL BARS

L. W. Krum, formerly observer foreman, metallurgical department, South Works Carnegie-Illinois Steel Corp., Chicago, has been transferred to the Lorain Division, Johnstown, Pa., as assistant to the superintendent of steel foundries.

K. W. Hathaway has been placed in charge of a newly opened office of Revere Copper & Brass, Inc., in Dayton, Ohio.

N. E. Dunning has a position as construction engineer with the Hercules Powder Co. at the new smokeless powder plant near Radford, Va.

Frederic H. Wright has left the U.S. Assay Office in New York to enter the Bureau of Mines Eastern Experiment Station at College Park, Md.

Ralph H. Houghton has been transferred from the chassis engine department of Packard Motor Co. to the aircraft engine division, metallurgical department, as a metallurgist.

William R. McCormick has accepted a position as metallurgist in the metallurgical department of the National Tube Co., Ellwood Works.

Promoted by American Steel & Wire Co.: **Earl H. Dick**, from works metallurgist to superintendent of wire and wire products, Donora Steel and Wire Works.

Stanley D. Zemansky, formerly assistant research engineer, North American Aviation, Inc., Inglewood, Calif., is now process engineer in Dallas, Texas.

H. L. Brunner is on leave of absence from Jones & Laughlin Steel Corp., serving as U.S. Army inspector at the Ravenna Ordnance Plant, Ravenna, Ohio.

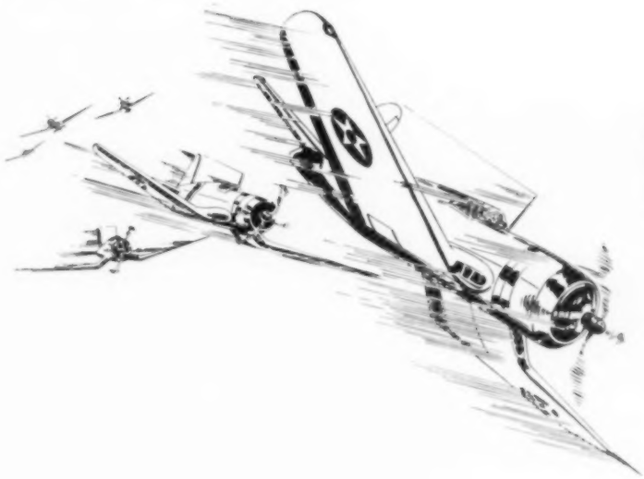
L. E. Simon, formerly metallographer with General Motors Research Laboratory, is now metallurgist, Special Engines Division, Electro-Motive Corp., La Grange, Ill.

FAHRITE

HEAT AND CORROSION RESISTING ALLOYS

for

NATIONAL DEFENSE



One of the many FAHRITE
Heat Resisting Castings
Contributing to
Defense.

PLANTS:
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SPRINGFIELD, OHIO

SALES OFFICES:
NEW YORK CITY
PHILADELPHIA, PA.
CHICAGO, ILL.
CLEVELAND, OHIO
TULSA, OKLA.
HOUSTON, TEXAS
NEW ORLEANS, LA.
LOS ANGELES, CALIF.
TOLEDO, OHIO
DETROIT, MICH.

THE OHIO STEEL FOUNDRY CO.
LIMA, OHIO • SPRINGFIELD, OHIO

PERSONALS

Frederick W. Schiefer is now general manager of the F. W. Schiefer Machinery Co., Rochester, N. Y.

Paul G. Nelson is now employed at Budd Mfg. Co., Philadelphia, as stainless steel metallurgist.

G. H. Bendell has been transferred by American Steel & Wire Co. from superintendent at Waukegan Works to assistant general superintendent of Joliet (Ill.) operations.

William G. Brown, formerly foreman, Winchester Repeating Arms Co., New Haven, Conn., is now superintendent of the casting shop for Allied Brass Limited, Montreal.

G. Lewis Perkins, formerly with Rustless Iron and Steel Co., is now in the metallurgical laboratory, Newburgh Works, American Steel & Wire Co., Cleveland.

Thomas F. McCormick has been made chief plant metallurgist of the Lafayette Works of the Aluminum Co. of America in Lafayette, Ind.

Andrew W. Hamilton has been graduated from the Army Industrial College in Washington, D.C., and is now stationed in Philadelphia engaged in procurement of ammunition.

Richard M. Jansen, formerly with Steel Tank & Pipe Co., Berkeley, Calif., is now employed as an engineer with the Southwest Welding and Mfg. Co., Alhambra, Calif.

Marshall G. Whitfield, formerly with Reynolds Metals Co., has gone into consulting work with **V. Sheshunoff** on aluminum coated steel and allied problems.

Gerald D. Rahrer has been transferred from the U.S. Steel Research Laboratory at Kearny, N. J., to the Research Laboratory of the Gary Works, Carnegie-Illinois Steel Co.

Lorenz W. Rinek, formerly metallurgical observer in the Universal-Cyclops Steel Corp., Bridgeville, Pa., has been called to extended active duty as 2nd lieutenant in the Ordnance Department, U.S. Army, and is scheduled to go to Fort Bliss, Texas.

George V. Darchuk is working for the National Advisory Committee for Aeronautics as a junior mechanical engineer on the engine research laboratory being built in Cleveland.

J. Louis Bauer, Jr. is on leave of absence from Standard Oil Co. of New Jersey, and is serving as 2nd lieutenant in charge of the Blacksmith and Welders School of the Quartermaster Replacement Center, Camp Lee, Va.

DURALOY

CHROME IRON CHROME NICKEL CASTINGS

SOUND CASTINGS

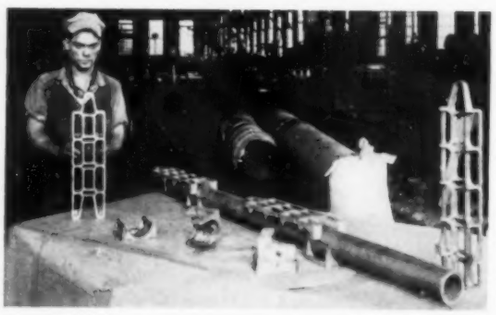
because they're Experienced Castings

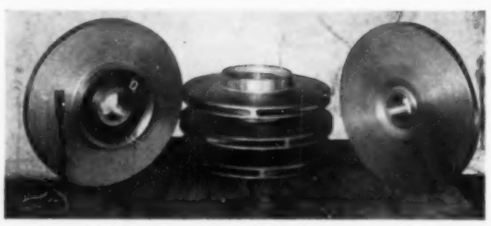
High temperatures and corrosion play no favorites. They attack and keep on attacking the castings used in equipment and parts. There's no let-up.

Only sound castings can survive these attacks. Analyses and grain structures must be right.

Granting these premises, don't you think that your best bet on high alloy castings is to go to experienced chrome-iron and chrome-nickel metallurgists and foundrymen?

Duraloy offers 19 years' experience in this exacting work.





THE DURALOY COMPANY

Office and Plant: Scottdale, Pa.
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pecial Quality"

TOOL AND ELECTRIC FURNACE ALLOY STEELS

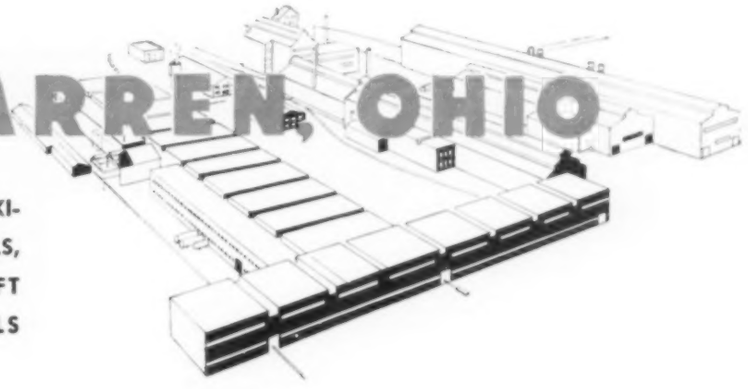
ARISTOLOY "Special Quality" Tool and Electric Furnace Alloy Steels are the product of an experienced organization of specialty alloy steel-makers—working in a modern plant especially designed and equipped for the efficient production of high-grade electric furnace alloy steels.

Aristoloy "Special Quality" Electric Furnace Steels include Tool Steels, Stainless Steels, Oxidation and Corrosion Resisting Steels, Aircraft Quality Steels, Valve Steels, Special Steels, etc.

Aristoloy "Special Quality" Tool and Electric Furnace Alloy Steels are melted in small furnaces ranging from 6 to 35 tons (rated capacities), and cast in small ingots using stationary molds and twin nozzle teeming. Our ample heating and rolling capacity, producing a wide range of sizes, can handle the entire electric furnace output. A modern metallurgical and chemical laboratory, centrally located within the plant, controls the quality factors in all operations.

Aristoloy "Special Quality" Tool and Electric Furnace Alloy Steels are available as Blooms, Billets or Bars—Hot-rolled, Annealed or Normalized, Spheroidized-annealed, Heat-treated, Straightened, Turned, Centerless-ground, Cold-drawn, or in any combinations of these conditions and finishes. Blooms and Billets may be either rolled or pressed.

OMPANY WARREN, OHIO



SPECIAL QUALITY BILLETS AND BARS, OXIDATION AND CORROSION RESISTING STEELS, TOOL AND SPECIAL STEELS, AIRCRAFT QUALITY STEELS, STAINLESS STEELS

WORK HARDENED ROPE WIRE*

By E. M. Trent

WIRE ROPE used in mining, in particular haulage rope, is subject to severe wear in service, which reduces the cross-section of the outer wires, and gradually reduces the strength of the rope. A more serious effect is the formation of a brittle surface on the wire, wherein cracks form and these can lead to the rapid failure of the outer wires before they have been seriously reduced in cross-section.

This type of deterioration is difficult to detect by inspection, and is therefore more dangerous. Examination under the microscope shows a layer of martensite, of maximum thickness approximately 0.003 in., covering part of the worn surfaces.

The area covered by any one layer of martensite on the worn surface is comparatively small and is in the form of a narrow strip extending in the direction of rubbing, that is, along the axis of the rope. In lang-lay rope the strip extends diagonally across the worn surface of the wire. The small size of the martensitic areas indicates that the area of contact between the wire and the rubbing agent is very small and thus the local pressure may be very high.

Sometimes several layers of martensite are produced one on top of the other, the last layer formed in each case tempering the layer immediately preceding it. From this, some estimate of the temperature gradient caused by the friction may be made; it is about 275° F. per 0.001 in.

Heating and cooling of the surface layer must take place in a very short space of time — a few seconds if not less. The transformation on heating to austenite must proceed very rapidly, facilitated by the fact that in rope wire the carbide is *very* finely dispersed. The microstructure of the sorbite (fine pearlite) is either not resolvable or only just resolvable at a magnification of 1000 diameters. Coarser carbides would require either a longer time or a higher temperature for their complete absorption into austenite. Where there are ferrite streaks at the grain boundaries, these are frequently not dissolved into the austenite on heating, and are visible in the martensite.

(Continued on page 748)

*Abstracted from "The Formation and Properties of Martensite on the Surface of Rope Wire", by E. M. Trent, British Iron and Steel Institute Advance Paper, May 1941.

ROUND PEGS

for round production holes

If there were just *one* stainless and heat-resistant steel, instead of dozens of variations, life would be simpler for us and a lot tougher for you. In fact, after one trial, you'd probably swear off stainless forever.

But we make stainless *to fit*—produce it with the proper analysis, physicals, etc. to meet the eventual conditions of service, yet fabricate easily and inexpensively in your plant. And we *continue* to produce your particular grade in close uniformity, lot after lot.

That's a job which calls for the technical skill and experience of a pioneer. It's something for you to remember, along with the fact that Allegheny Stainless is produced in every needed form or shape, and available from convenient stocks nationwide.

ALLEGHENY LUDLUM STEEL CORPORATION · GENERAL OFFICES: PITTSBURGH, PA.

Stocks of Stainless carried by all Ryerson Warehouses

★ ★ ★ AL ALLEGHENY LUDLUM STAINLESS STEELS PRE-PLANNED TO YOUR NEEDS ★ ★ ★

Write for a copy of our new "Handbook of Special Steels." Send the coupon to Allegheny Ludlum Steel Corporation, Oliver Building, Pittsburgh, Penna.

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LITERATURE

Special Steels

An attractive, helpful 124-page handbook containing the properties, uses, and fabricators of stainless, electrical, carbon and other steel manufactured by the Allegheny Ludlum Steel Corp. is available. Bulletin De-92.

High Speed Steel

A new 12-page booklet which describes Jessop's Mogul molybdenum-tungsten high speed steel has just been published by the Jessop Steel Co. Bulletin De-173.

Free Machining

Reserve your copy of new twenty-page story of Speed Case and Speed Treat. This booklet covers physical properties, compares this W. J. Holliday & Co. steel with SAE 1320 and others. Explains how manganese and sulphur content plus efficient manufacturing processes produce free machining combined with comparatively high physical values. Also contains machinability carburizing tables and pictures applications. Bulletin Kd-293.

Steel Data

Ten colorful leaflets each describing a popular grade of tool or high speed steel and giving useful data, has been issued by Vanadium-Alloys Steel Co. Write for Bulletin Kd-294.

18-8 Types

Properties, fabrication, corrosion-resistance and applications of Republic Steel Company's ENDURO 18-8 are covered in a new 24-page booklet. Bulletin Be-8.

Hard Facing Alloys

For maximum resistance to wear and corrosion, the Wall-Colmonoy Corp. offers a fact-packed folder which is extremely helpful to anyone having this problem. Bulletin [illegible].

N-A-X

A twenty-page, fully illustrated booklet on N-A-X high tensile low alloy steel has been published by Great Lakes Steel Corporation. This steel has been thoroughly proved in applications where ordinary high tensile steels have failed. Bulletin [illegible].

Free Machining Steels

Speed Case and Speed Treat, two steels with increased machining properties, are described in literature available through Monarch Steel Co. Bulletin Cd-255.

Welded Stainless Tubes

A really striking 16-page booklet containing 45 illustrations on Welded Stainless Tubing is offered by the Carpenter Steel Co. Bulletin Kd-12.

Steel Data Sheets

Wheelock, Lovejoy & Co. gives analyses, physical properties, heat treating instructions and applications of Hy-Ten, Ex-Cromo, and S.A.E. alloy steels in convenient and easily available form. Bulletin Ox-74.

Columbium

"Advantages of Columbium in Wrought 4 to 6 Per Cent Chromium Steel" is the title of a booklet made available through the Electro Metallurgical Co. which gives detailed test data to prove its advantages. Bulletin Cc-16.

Cr-Ni-Mo Steels

A Finkl & Sons' catalog is really a technical treatise on chromium-nickel-molybdenum steels for forgings. Pocket size, 104 pages, cloth bound, illustrated by photographs, charts and tables. Bulletin La-23.

Meehanite Castings

An interesting, well-illustrated 49-page booklet, "Meehanite in Industry", covering applications of Meehanite castings in a variety of industries is now available through the Meehanite Research Institute of America, Inc. Bulletin Ce-165.

Melting • Casting

Core Making, Baking

A very striking new 14-page folder released by the Despatch Oven Co. will be helpful to those engaged in core making and baking because it explains fundamentals of good core making and shows better ways of handling cores. Bulletin Ee-123.

Foundry Sand

A pamphlet issued on TAM Foundry Zircon Sand and TAM Zircon Flour contains detailed information on these products of the Titanium Alloy Mfg. Co. Bulletin Hc-90.

Aluminum Castings

An aluminum casting alloy is announced by the National Bronze and Aluminum Foundry Co. of Cleveland. Known as the T-1 aluminum alloy, it has a tensile strength up to 33,000 psi. without heat treatment. A folder gives complete data, composition and detailed information. Bulletin De-307.

Diecasting Machines

A new high-pressure hydraulic diecasting machine specifically designed to solve modern production problems is illustrated and discussed in an imposing new folder by the G & N Mfg. Co. Bulletin Ee-308.

Finishing • Plating • Cleaning

Degreaser

Degreasing machines for practically every cleaning job are described in literature made available through the Detroit Rex Products Co. Bulletin Hc-111.

Rust Preventative

How to prevent rust effectively is related in a bulletin issued by the Alox Corp. Describes their method which is being used successfully in a wide variety of forms. Bulletin Nb-212.

Cadmium Plating

Concise, practical information for the operating plater is included in an up-to-date manual on cadmium plating released by E. I. DuPont de Nemours & Co., Inc. Bulletin Hd-29.

Rocker Barrels

The operation of cleaning miscellaneous items of gray iron, steel, semi-steel malleables, forgings, plate, bars, bronze and other castings by the Airless Rotoblast method is described fully in a handsome booklet by the Pangborn Corp. Bulletin Ae-68.

Mounted Wheel Chart

A convenient ready reference wall chart showing mounted grinding wheels should be of great advantage in the cleaning room, pattern shop, tool and die room, and many other places. It gives at a glance, by means of detailed drawings, actual size, the exact radius of each wheel and its exact shape. Chicago Wheel & Mfg. Co. Bulletin Bd-230.

New Cleaning Process

A new process for cleaning brass, copper and zinc alloys before plating to provide better removal of oil, grease, smutty deposits and soap films to assure better plate adhesion is described in Oakite News Service, house magazine of Oakite Products, Inc. Bulletin De-296.

Rotary Files and Burs

A variety of high-speed Rotary Files and Burs plus other necessary shop equipment is included in the complete catalog available through the Martindale Electric Co. Bulletin Kd-282.

Metal Blackout

The JETAL process for blackening iron and steel quickly and thoroughly at low cost is described in literature available through the Alrose Chemical Co. Bulletin Cd-256.

Heat Resistant Metals

Heat and Corrosion

A catalog showing various uses of Fahrite to resist heat and corrosion has been prepared by the Ohio Steel Foundry Co. Bulletin Kd-40.

X-Ray Inspected Castings

All types of heat and corrosion resistant castings made with extensive use of "X-Ray Inspection" and modern foundry methods are shown and described in a 16-page two-color booklet made available by the Electro-Alloys Co. Bulletin Ld-32.

Heat Resisting Alloys

Authoritative information on alloy castings, especially the chromium-nickel and straight chromium alloys manufactured by General Alloys Co. to resist corrosion and high temperatures, is contained in Bulletin D-17.

Refinery Alloys

Special alloys for refineries, corrosion, temperature, and abrasion resisting are covered in a colorful folder produced by the Duraloy Co. Bulletin Kd-233.

High Temperature

High temperature uses of Monel, Nickel and Inconel are analyzed and pictured in a recently printed bulletin released by International Nickel Co. Bulletin Kd-45.

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Page 745				Page 746				Above			
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Ce-67	Oy-140	Ld-41	Ae-300	Dd-41	Na-138	De-100	Ic-126	De-173	La-23	Hd-29	Kd-40
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De-213	Fe-157	Fe-310	Ge-132	Ee-192	Ea-5	Nd-66	Be-239	Kd-294	Ee-123	Ae-68	Ld-32
De-303	Kd-21	Ce-81	Ae-297	Nc-154	Be-30	Ld-57	Hd-9	Be-8	Hc-90	Bd-230	D-17
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		Ee-114		Ee-218	Nd-123	Dd-260		Cd-255			
						Be-301		Kd-12	Ee-308		

ROPE WIRE

(Continued from page 740)

In rubbing against any metal object the rope wire may seize onto it, and this leads to the rapid wear both of the rope and the other object. Particles of metal may be welded onto the rope wire by the high pressure and temperature, and microscopic examination may indicate the nature of the material against which the rope was rubbing.

These thin layers of martensite are very brittle and can withstand very little, if any, plastic deformation. Thus it is usual to find it to contain numerous cracks. Once a crack is formed it acts as a stress raiser. The bending stresses induced in the wire are concentrated at the base of the crack, which is rapidly deepened by repetition until the wire breaks.

Cracks are most frequently found at or near a point where a layer of martensite has been reheated by the overlapping of a second layer. Thus, sufficiently high rubbing stresses may, by themselves, cause failure (perhaps by a wedging action) even though the actual loads on the rope are safe and the pulley diameters sufficiently large.

Martensitic layers produced in the laboratory by striking the wire a glancing blow were easily cracked by bending the wire through an angle of 20° over a ½-in. radius. In the reverse-bend test over a 5-mm. radius, a wire with martensite on the surface broke after seven bends, while a wire without martensite withstood nine or ten bends.

A full series of fatigue tests might compare wires with and without martensitic coatings. Our less exhaustive results, however, indicate that a martensitic coat, starting without cracks, has little influence on the fatigue limit or on the number of reversals to failure up to a stress of approximately 100,000 psi. However, if the martensite were cracked before the test the fatigue limit would be greatly lowered, since these cracks would act as stress raisers. Also, if the reversed stress were raised to a point where the plastic deformation of the wire itself was comparatively large, the martensite, being unable to deform plastically, would be cracked during the first few reversals of stress and the wire would fail rapidly.

The martensitic coating appeared to have little effect on the tensile strength or on the torsion test.

Under certain conditions of corrosion the presence of martensite containing cracks leads to the formation of corrosion pits on the worn surface of wire. When these pits take the form of "chain pitting" they indicate that martensite is probably present.

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good union between layers and minimize the danger of layer cracks in the finished lining.

REFRACTORY MATERIALS

Fused magnesia, which is especially suitable for melting metals, both ferrous and non-ferrous in electric induction furnaces, has a melting point of 2350° Centigrade. It is exceedingly high in heat conductivity and electrical resistance. The coefficient of expansion is 0.0000135 cm. per degree Centigrade. It has a hardness of about six. It is furnished in various forms but usually as a cement composed of the refractory magnesia grains plus suitable ceramic bonding material.

CRYSTOLON, or silicon carbide cements are particularly suitable for lining pit furnaces and crucible furnaces and for making monolithic linings and for general tamping operations. CRYSTOLON cements can be made very dense and resistant to slag. They withstand thermal shock unusually well.

ALUNDUM or fused alumina cements are stable under oxidizing and other chemical conditions, they provide very good heat transfer and their resistance to high temperature is excellent. The fused alumina used in the preparation of these cements has a melting point of 2050° Centigrade.

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(Figures indicate approximate hardening temperatures)

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RA-1144 { 1000° C. / 1830° F.
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Brass alloy melting
Indirect arc furnace linings

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Monolithic linings
Patching

RC-1131 coarse { 1000° C. / 1830° F.
Pit furnace linings
Crucible furnace linings
Monolithic linings
Tamping

RC-1133 { 800° C. / 1460° F.
Patch cement
Pit furnace linings

RM-868 { 1200° C. / 2190° F.
Crucible linings

RM-1005 { 1200° C. / 2190° F.
RM-1114 med. coarse { 1200° C. / 2190° F.
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Electric induction furnace linings in ferrous and non-ferrous melting

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RM-1140 { 1200° C. / 2190° F.
RM-1162 { 1200° C. / 2190° F.
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CREEP OF LEAD *

By J. Neill Greenwood and H. K. Worner

CREEP is partly a "viscous" movement and partly crystalline slip, so the limit of proportionality can be taken as an approximate guide to the critical stress above which crystalline slip becomes effective. It was thought that lead would be a good metal to investigate the viscous movement, but the experiments showed creep curves of rolled lead and its dilute alloys under prolonged stress are of four distinct types.

Three leads were studied, a very pure electrolytic lead with total impurities equalling 0.0004%, lead SA with 0.0023% impurities, and lead U with 0.0023% bismuth, 0.0042% antimony, 0.0003% silver and 0.0015% other impurities.

Creep curves of Type A showed marked strain hardening in the early stages after which recrystallization occurred. Peaks in the curves correspond with re-orientation of the crystals in the specimen. Near the end of the test, several marked decreases in the creep rate were observed and, although this has been observed frequently, no satisfactory explanation has been found. Test pieces eventually fail in a ductile manner, neck and draw out to a knife-edge.

In curves of Type B the creep rate first increases and later changes to the strain hardening type, and there are no deviations due to re-orientation. If lead is quickly cooled from 250° F. and a creep test (loaded over the critical stress) is started within two days, the creep rate increases at first and this period is followed by strain hardening. There is no recrystallization, and the piece fails by intercrystalline cracking. A reversion to type A or D occurs if the specimen is allowed to stand at ordinary temperatures before stressing.

In curves of Type C the creep rate continues to increase from the beginning. Test pieces generally fail with greater elongation than Type A samples, even though they developed marked intercrystalline cracking and very little reduction of area at the fracture.

Type D is the normal strain hardening type of creep curve obtained with metals which are

(Continued on page 760)

*Abstracted from "Types of Creep Curve Obtained With Lead and Its Dilute Alloys", by J. Neill Greenwood and Howard K. Worner, *Journal* Institute of Metals, vol. 64, page 115, 1939.

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CREEP OF LEAD

(Continued from page 756)

below their recrystallization temperature.

Above the critical stress, pure lead and certain dilute alloys give a strain hardening type of curve showing a marked deviation due to the increase of creep rate during recrystallization. The degree of purity of "pure" lead and the particular elements present as impurities have a marked influence on the creep rate above the critical stress and on the percentage of strain required to cause recrystallization under stress. The purer the lead, the smaller the deformation that will be required to cause recrystallization.

Up to 0.01% bismuth and antimony had little effect, while copper, zinc, and silver appreciably increased the deformation necessary for recrystallization. Even 0.001% zinc and silver had a marked effect.

The addition of solute atoms to lead causes a change from Type A to Type D curve, the lattice being stabilized. There is then no recrystallization during the test. If an alloy is cold worked and the work hardness is lost during the test, a continuous increase in creep rate is found — Type C curves. This type of curve is also associated in an undetermined manner with the presence of certain solute atoms. Type C curves are more pronounced the lower the stress and the higher the concentration of the solute.

The grain size of pure lead stressed above the critical stress, if between 0.5 and 5-mm. diameter, has little effect on the creep rate prior to recrystallization.

Creep is complicated in many ways by the presence of solute atoms. For example, grain size, hardness, and work hardening capacity are all changed. Neither hardness nor work hardening capacity is a criterion of the behavior under prolonged stress, but rate of recovery after work hardening is sometimes an important factor. Another complexity arises from the mode of distribution of the added element — whether solid solution, eutectic, or as primary crystals either in the elementary or in the combined form.

Two important problems must be further considered: *(a)* The influence of solute concentration, and *(b)* the influence of degree of dispersion of a second phase. Solute atoms may cause an increase or a decrease in the creep rate above the critical stress.

Vibration markedly increases the creep rate of lead and causes recrystallization to take place after smaller amounts of deformation.

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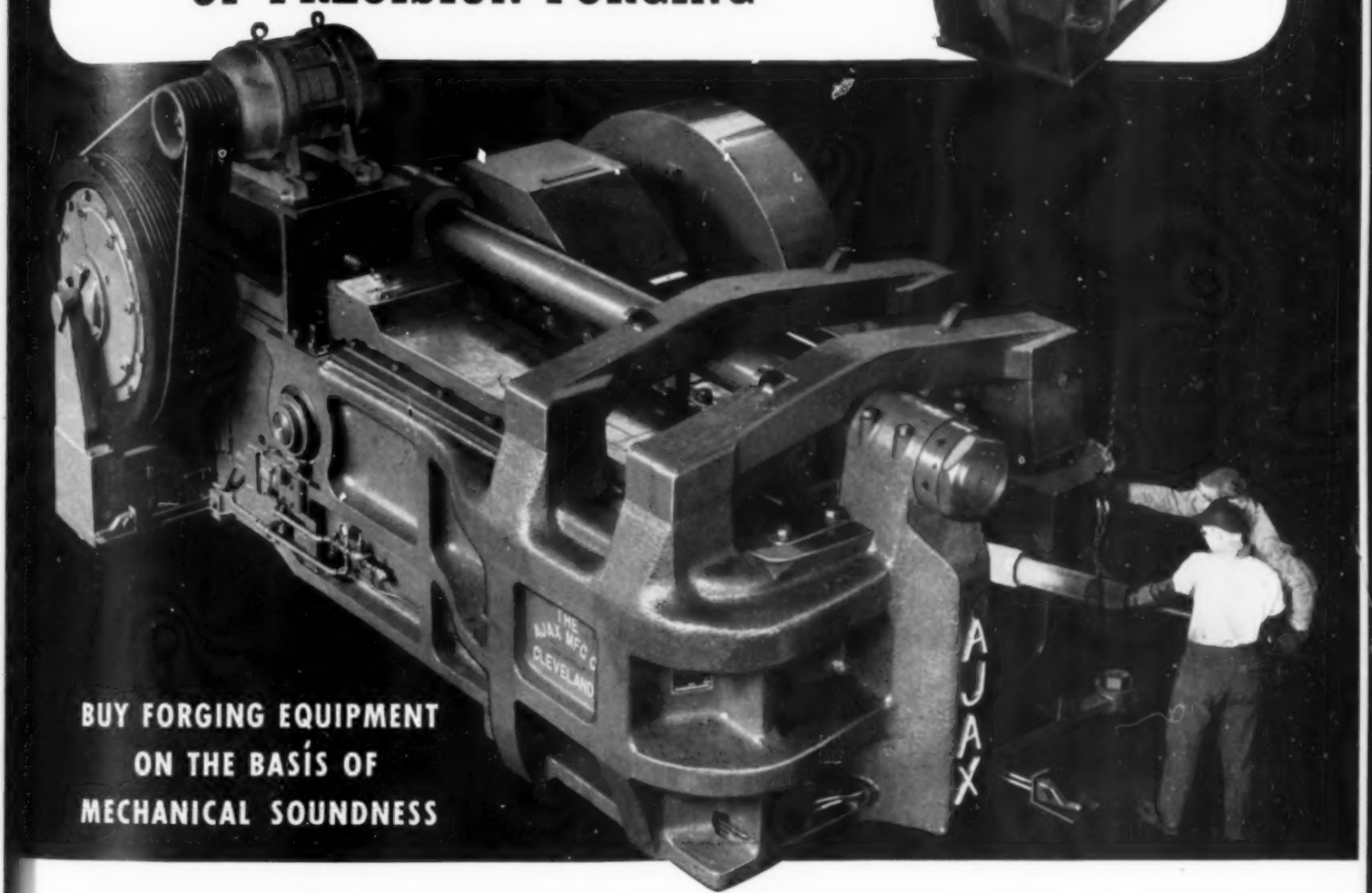

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INSPECTION

(Continued from page 709)

to improve the performance of the machinery and materials furnished to the Navy. Here the specifications are written around the experience of over a hundred years in the use of various materials at sea.

A most important aid is the fleet itself, which is a laboratory on a grand scale. Officers submit reports periodically on the behavior of materials and machinery under the various conditions of operation. This enables the technical bureaus to improve design, select materials better suited for service, change material specifications and methods of inspection or test, and keep the inspection service informed.

Dependable material, free from injurious defects, is a necessity for naval construction. Here we are concerned with materials for fighting ships as distinguished from materials for ordinary commercial purposes, although many are in common use by both. Naval shipping demands are more rigid than those encountered in commercial practice for similar materials because they have to withstand much more severe service and additional loads and stresses due to rapid changes between low and full power, to temperature operating conditions, to working of ships in heavy seas, to vibration shock by gunfire, torpedoes and aerial bombs, to unevenly applied torsional loads as in propeller and main machinery shafting, to defects of lubrication on account of the pitching and rolling of the ship, and to corrosion and corrosion fatigue of metals exposed to salt water or salt-laden atmosphere.

Casualties or breakdowns may not be serious to shore installations, where, by merely utilizing the telephone, replacements may be expected on short order. On a ship at sea, such prompt service cannot be rendered and certain types of material defects may lead to serious casualties, endangering not only the lives of the operating personnel, but also the ship itself. In the event of war the time for making replacement is a most precious and priceless thing.

It must be remembered that ships of the U. S. Navy range from the arctic to the tropics, and must be prepared to operate as efficiently with the temperature at 105° topside and possibly 140° or 150° F. in the engine-room, as when the temperature is 20 below and ice has formed a cloak around the ship. This requires the finest of materials and the most careful inspection it is humanly possible to make.

In addition to the foregoing military reasons for inspection, the method of making Government purchases and awarding

(Continued on page 776)

Liquid SALT BATHS

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Modern salt bath treatment is not limited to steel. Aluminum alloy aircraft parts, for example, must be heat treated to distribute the alloying materials throughout the metal in their most effective form. The liquid salt bath is most suitable for this purpose. Residual salt on sheets or parts serves to hold the heat on thin sections between the bath and the quench, preventing precipitation of copper.

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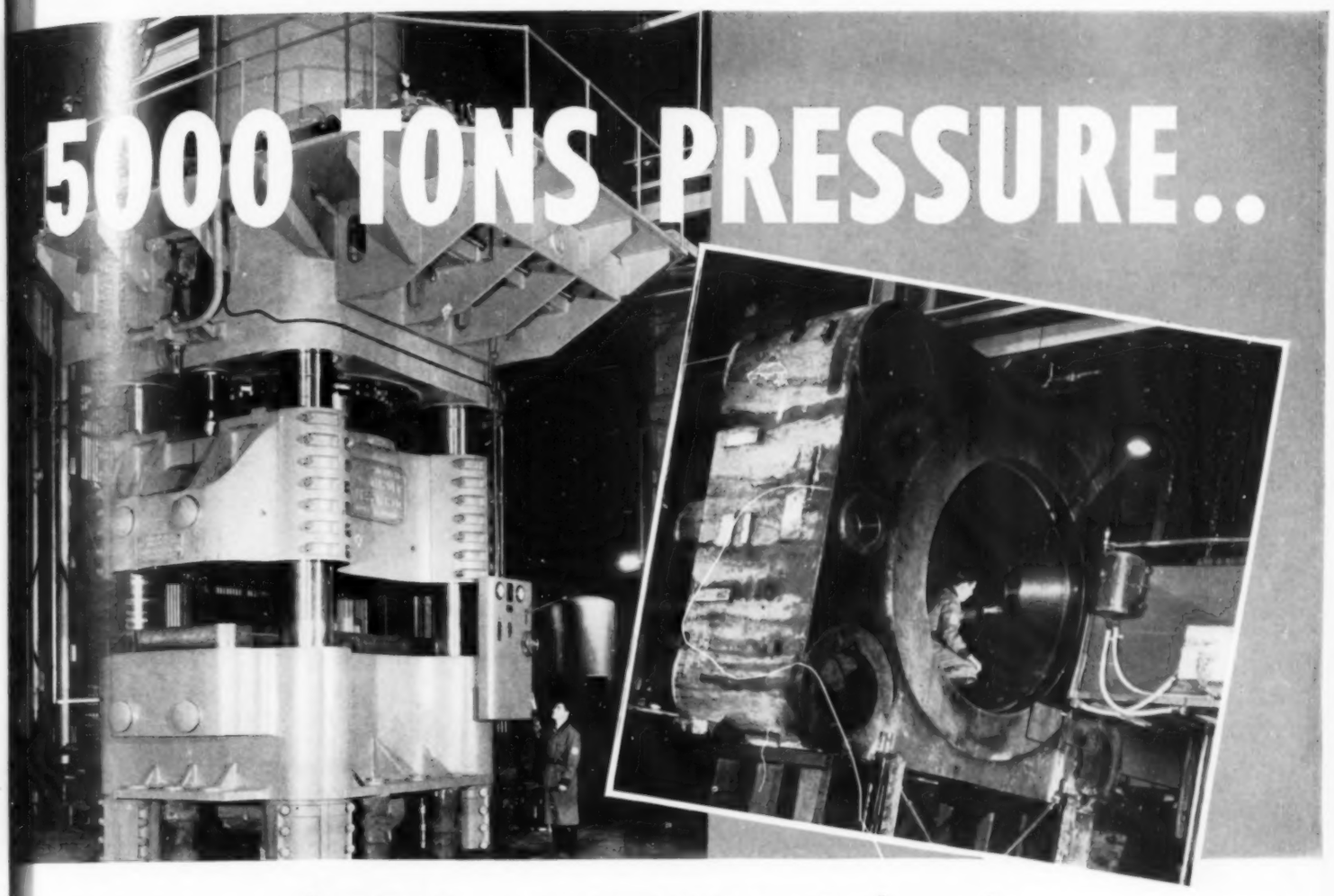

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H-P-M engineers say—"We do not believe that any other material could possibly stand up as well as cast steel under the tremendous pressures and strains involved, still maintain precision alignment, give adequate rigidity and resist fatigue.

"And certainly no other material or process would contribute so much saving of time, work and cost in building the press itself."

Whatever *you* make, look into steel castings when writing your specifications and planning your production. Steel castings bring you strength where you want it, without excess weight. They bring you a wide choice of mechanical properties, ease of machining and finishing, combinations of parts that save handling and assembly time—all contributing toward a better finished product at lower cost.

For more information, consult your local foundry, or write to Steel Founders' Society of America, 920 Midland Bldg., Cleveland, Ohio.

FOLLOW THE EXAMPLE OF THE MODERN PRESS BUILDER — MODERNIZE YOUR PRODUCT WITH

STEEL CASTINGS

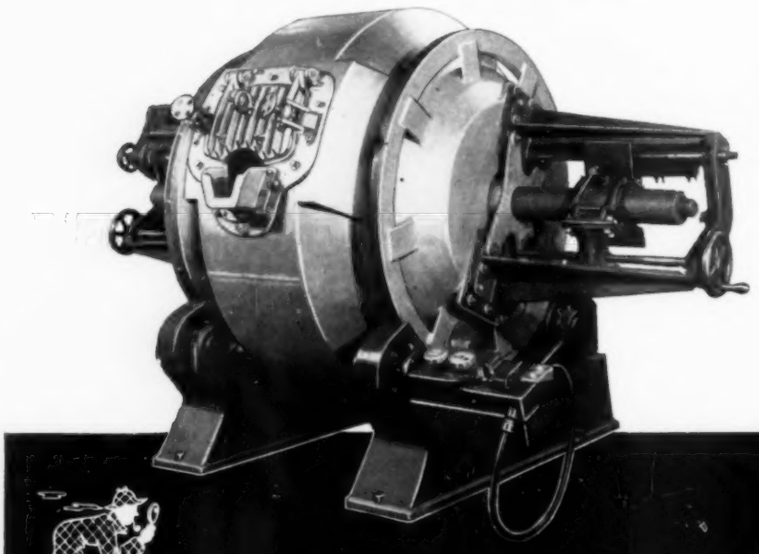
INSPECTION

(Continued from page 768)

contracts to the lowest responsible bidder renders it imperative to conduct the inspection at source of manufacture and to make the necessary tests of practically all contracted materials, of which there are several thousand varieties.

Today most large industrial establishments have found it necessary, for efficiency and to protect their financial interests, to maintain an inspection department of their own. Railroads, for instance, require inspection at source not only to avoid loss of life, but also to avoid heavy damage awards resulting from law suits. In contrast to former days, when the presence of a Naval Inspector in a shop for inspection purposes was looked upon with apprehension and to be suffered only, he is welcomed today by manufacturers who have faith in their product and the knowledge that the inspector is there to cooperate with them in producing satisfactory materials. The inspector is an added protection to the honest manufacturer, since he requires all who supply materials for the Navy to conform to the specifications on which the lowest responsible bid was based. This sometimes forces a less scrupulous contractor to throw up the contract after discovering that he must and will be required to furnish the material exactly in accordance with the specifications on which he has bid, and will not be permitted to furnish a cheap and inferior material. In such cases the Bureaus are empowered by law to buy material in the open market which conforms to the specifications and to charge the manufacturer with the difference in price between the bid price and the market price. This seldom occurs twice to the same contractor (perhaps because he is not permitted to bid again until he has shown his responsibility).

There are many manufacturers who give full cooperation to the Government — whose products require a minimum of inspection as to quality, and who are entirely dependable. The products of these might actually need no inspection, but the Government is doing business with several thousands of manufacturers, many of whom are furnishing materials or services for the first time. Some few have used questionable materials and methods. To be fair to all, no one can be excused from inspection of his products. The results of an error would be too great and entirely unwarranted to the National Defense. The Navy must be the final judge, as it has the actual operating experience and is more fully cognizant of its own needs than the manufacturer.



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CAUSTIC EMBRITTLEMENT

(Starts on page 696)

by reaction of the steel with the highly concentrated alkali solution found in the riveted joints or boiler seams.

German engineers hold the steel responsible for the failures and insist that, to be satisfactory, the steel must be specially resistant to corrosion under the extreme conditions of temperature and pressure it is called upon to withstand. Considerations of this kind led to the development of "IZETT non-aging steel", which was claimed to be immune, but which failed in the same way as mild steel when tested under American conditions.

It is by no means shown by the evidence brought forward that intercrystalline cracking is dependent on susceptibility to aging embrittlement. On the other hand, it cannot be denied that the primary cause of aging, that is, appreciable permanent deformation of the metal, is present round most holes. Aging may be considered as a contributory factor to embrittlement, though its importance is probably not as great as once supposed.

DESCH considers the term "caustic embrittlement" incorrect, as the steel between the cracks is not necessarily brittle. Cracking which occurs in certain chemical plant presents such a close resemblance to the cracking of boilers as to suggest a similar origin. At least in most of their course, the cracks follow the boundaries between the crystal grains. In this they differ from fatigue cracks, which take by preference a path through the crystal grains, and from grooving caused by acid corrosion, which takes an irregular path, independent of boundaries.

A striking instance of cracking caused by nitrates occurred in 1917. In this failure there was no liquid present in quantity, and the steel shells (used for drying moist crystals of ammonium nitrate) were surrounded by a jacket containing steam at only 30 psi. pressure, so that there was no excessively high temperature. The cracks started from rivet holes, but usually ran transversely across the shell plates, taking a markedly intercrystalline path, deflected here and there by numerous non-metallic inclusions. The life of the vessels had been very short. They had been repeatedly cooled by fresh charges of moist salt, the tem-

(Continued on page 784)

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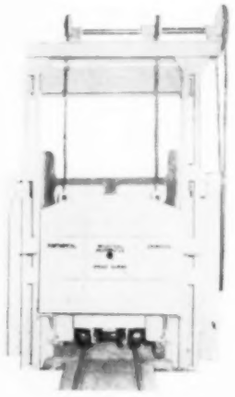
ARMOR PLATE, GUN CARRIAGES,
AIRPLANE PARTS



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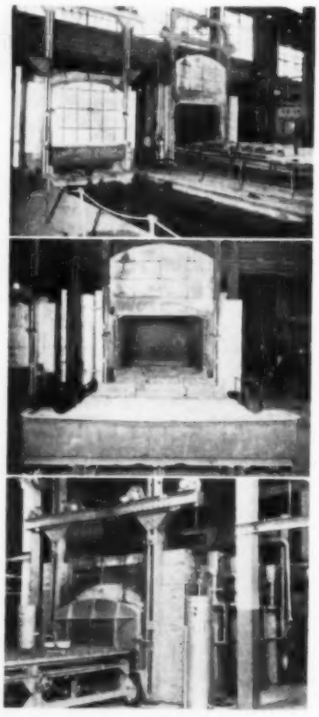

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DEFENSE AND THE FUTURE...

Copy of Letter to users of Products of The International Nickel Company, Inc.

The International Nickel Company, Inc.

EXECUTIVE OFFICES: 67 WALL STREET

ROBERT C. STANLEY, PRESIDENT

New York, April 17, 1941.

Dear Sir:

Our plants, in common with those of most of America's industrial units, are working at their peak on defense production. In spite of this, hardship is being inflicted upon many consumers of our products who in the past have aided us in building a great business, and upon whom we must depend for our future success.

As this letter is written the monthly production rate of The International Nickel Company of Canada, Limited is already 20% above last year; three times that of 1929 and four times the peak rate of the last war. Its facilities have been increased to supply current defense demand and further increase in output will be available this year.

Upon the conclusion of this devastating war the future success of your business and ours will depend in large measure upon the retention of the good will of our customers. Any effort we can make, not conflicting with our full support of the defense program, should be directed toward this vitally important objective.

To this end we wish to offer our services especially to those customers whose requirements cannot for the moment be filled. One practical means of rendering such service is to offer you the assistance of our technical staff in solving problems of material arising from the temporary lack of nickel.

Our problems are complex and constantly changing and can only be solved through cooperation. As we see it, a large part of the solution lies in making clear the situation which we face. Your help and advice will be of invaluable assistance. It is our purpose to follow this letter with a personal call from one of our representatives, if you so desire, who will discuss with you in more specific detail our mutual problems.

Yours very truly,

R C Stanley

PRESIDENT.

RCS:JJS

BRITTLENESS

(Continued from page 780)

perature then rising gradually, but any stresses so produced must have been far below the yield point. The rapid failure may have been connected with the inclusions, indicating poor quality; the metal probably opened up at these internal stress-raisers during the "breathing" of the vessels. This illustrates the rapid action of ammonium nitrate on the intercrystalline boundaries in steel at moderate temperature.

The contradictory nature of the results obtained by different investigators of caustic embrittlement is striking, and shows that several factors are involved which are difficult to keep constant while a single factor is being studied. A few general conclusions may be drawn:

1. Intercrystalline cracking in steam boilers is always associated with a high alkalinity of the water. Where this is unavoidable, owing either to the originally alkaline character of the water supply or to the softening process which has been applied to a naturally hard water, the proven method of protection is the maintenance of a ratio of sulphate to alkali above a certain value, depending on the working pressure.

2. The steel must be in a condition of stress, either through an external constraint (as in a riveted joint which has been forcibly bent) or by internal stress — as in a rivet or plate which has been subjected to a high riveting pressure.

3. There must be opportunities for the concentration of the solution in capillary spaces, as at riveted joints. A seamless drum presents no such cavities, and caustic cracking has not been observed in such drums.

4. A high temperature must be reached. This, however, depends on the composition of the solution. Cracking may occur at or near 100° C., or it may need a much higher temperature. It should be pointed out that temperatures much in excess of the working temperature of the boiler may be reached in a riveted butt strap joint exposed to the flame.

5. The cracks are not to be attributed to corrosion fatigue, as has sometimes been maintained. Corrosion fatigue may produce cracks, but they usually pass through the crystals and not around them. The two kinds of defect may ordinarily be distinguished by simple inspection, but a microscopic examination is quite decisive.

6. Both hydrogen and the deposit of iron oxide formed by the reaction play a part in the process, but the mechanism remains unexplained.

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● The parts shown above were cut in one eight-hour day on the DoAll. At least five days would have been required by drilling, shaping, milling and boring.

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